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Hydro-CH2018 Hydrological Scenarios

Swiss Water Bodies in a Changing Climate

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National Centre for Climate Services NCCS
The NCCS is the Swiss federal network for climate services. As a national coordination and innovation body and a knowledge platform, the NCCS supports climate-smart decision-making, so as to minimise risks, maximise opportunities and optimise costs.

PROTECTING CLIMATE IS PROTECTING WATER BODIES

With its rivers, lakes, groundwater resources, glaciers and snow-capped mountains, Switzerland is one of the most water-rich countries in Europe. But it is also a country whose resources are intensively used, and that applies particularly to its water bodies, which are under great pressure from abstraction, pollution, drainage and structural engineering. In recent decades, climate change has been added to this list.

What impact will climate change have on our water bodies and water management? This question was examined at the National Centre for Climate Services (NCCS) as part of the priority theme 'Hydrological principles of climate change' (Hydro-CH2018). The project presents a detailed picture of how Switzerland's water balance is expected to change by the end of this century and how water bodies will be affected. Its findings are summarised in this brochure.

Bringing together some of the country's leading research institutions, Hydro-CH2018 provides incontrovertible evidence that the climate-related changes already observed in Switzerland's water balance are set to intensify in the future.

An effective climate policy is vital for water bodies as, without global climate change mitigation measures, watercourses in the Swiss Plateau would be up to 5.5 °C warmer in summer by the end of the century and only carry around half as much water as they do today. This would be hugely challenging for nature, society and the economy, all the more so because the demands on water bodies are increasing continuously, whether it be for cooling, irrigation, heat extraction or power generation.

Society and the economy must adapt to the new climatic conditions and also take the environment into account. However, the success of this adaptation will depend on having resilient water bodies capable of mitigating, to some extent, the additional challenges involved.

For this to happen, the applicable regulations on water protection must be implemented consistently in all areas as a matter of urgency. Climate change requires us to reappraise all our interventions, from water abstraction and pollutant inputs through to civil engineering measures. Our actions today will determine the future of Swiss water bodies.

Katrin Schneeberger, FOEN Director

THE WATER BODIES AT THE END OF THE CENTURY

Climate change will greatly affect water availability over the course of the year. The Hydro-CH2018 hydrological scenarios show that, at certain times and in certain regions, this vital resource will become so scarce or so warm that humans will have to curb their activities and nature will suffer. With climate change mitigation, the changes will be much smaller, meaning that such mitigation is worth the effort. Systematic protection of waters as well as careful planning and management will enable the challenges to be dealt with more effectively.

The overview shows the mean expected changes in 2070–99 compared with the reference period 1981–2010, with and without climate change mitigation. The values given are averages for the whole of Switzerland.

Runoff from snowmelt
–45 % without climate change mitigation
–15 % with climate change mitigation

Winter runoff
+30 % without climate change mitigation
+10 % with climate change mitigation

Annual runoff
–10 % without climate change mitigation
–0 % with climate change mitigation

CHANGES IN RUNOFF

As temperatures rise, snow and glaciers will gradually become less important as reservoirs. This will alter the seasonal distribution of runoff, with streams and rivers in Switzerland carrying more water in winter and less in summer than they do now. In addition, there will be more groundwater recharge in winter, but less in summer and autumn. However, annual runoff will only decrease slightly.

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Low flow in areas below 1500 meters a.s.l.
–30 % without climate change mitigation
–15 % with climate change mitigation

Summer runoff
–40 % without climate change mitigation
–10 % with climate change mitigation

WATER SHORTAGES IN SUMMER

Rivers and streams will carry less water in summer owing to the reduction in meltwater and precipitation as well as more frequent and longer dry periods. There will also be an increase in evaporation. As a result, the amount of water available in summer will decrease, while at the same time nature and society's need for water will increase.

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RESPECTING LIMITS ON USE

When temperatures rise, nature needs more water. Human use of water bodies must adapt to this additional demand or risk damaging ecosystems. Moreover, when water is scarce, certain uses must be prioritised over others. It is important to take a long view here, because hydraulic structures and operating licences can be around for many decades.

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MAKING WATERS MORE RESILIENT TO CHANGE

Ecologically intact and near-natural water bodies are better able to cope with the challenges of climate change. Streams, rivers, lakes and groundwater must therefore be kept in, or restored to, their natural state. It is also important to better protect water resources from excessive water abstraction and from contamination.

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100-year single-day precipitation event
+20 % without climate change mitigation
+5 % with climate change mitigation

Glacier volume Alps
–95 % without climate change mitigation
–65 % with climate change mitigation

GROWING HAZARD POTENTIAL

More frequent and intense heavy precipitation events combined with a higher zero-degree line will reinforce high-water levels, landslides and flooding. At high altitudes, glaciers will disappear and the frozen subsoil will gradually thaw. This will increase the likelihood of rockfalls, landslides and debris flows.

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Water temperature streams summer
+5.5 °C without climate change mitigation
+2 °C with climate change mitigation

Annual lake water surface temperature
+3.5 °C without climate change mitigation
+1 °C with climate change mitigation

AQUATIC LIFE AT RISK

Climate change will cause water temperatures to rise. This, together with low water levels, could have severe consequences for plants and animals living in and around waters, especially in summer.

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How were the hydrological scenarios generated? → Page **24**

Concerted climate change mitigation is vital for water bodies.

EVERYTHING IS FLOWING

Switzerland is one of the most water-rich countries in Europe. The Alps and its proximity to the Atlantic and Mediterranean means that more precipitation falls here than elsewhere. Switzerland also has large water reservoirs in the form of lakes, groundwater, glaciers and snow.

WATER CYCLE

Water moves in a global cycle. It falls from clouds to the earth as rain or snow, infiltrates the soil and groundwater or evaporates as water vapour, emerges from springs, flows in streams, rivers and lakes and finally reaches the ocean, where it rises back into the atmosphere.

Global warming is intensifying the water cycle.

SNOWMELT* 350 mm/year

At low temperatures, precipitation falls as snow and is stored in snowpack for a few weeks or months. In spring and summer, the snow from the previous winter melts, swelling the Alpine streams and rivers.

As a result of climate change, the contribution from snowmelt will decline sharply:
Winter –15 | Spring –54 | Summer –76 | Autumn –20
Year –165 (in mm)

*Snowmelt forms part of precipitation.

PRECIPITATION 1,440 mm/year

Switzerland receives a lot of precipitation, mostly in the mountains. The prevailing winds carry clouds from the Atlantic and Mediterranean to the Alps, where they cool down and release their water.

Owing to climate change, precipitation will increase in winter and decrease in summer, with more falling as rain instead of snow.
Winter +37 | Spring +21 | Summer –70 | Autumn –18
Year –30 (in mm)

Artificial reservoirs

Usable volume
3.5 km³/year

GLACIER MELT 10 mm/year

Glaciers can store precipitation for decades. In winter, they gain in mass, especially at higher elevations. The ice at lower elevations melts in summer and autumn.

Climate change means that glaciers will supply less and less meltwater, with most glaciers disappearing completely:
Winter +0 | Spring +0 | Summer –5 | Autumn –2
Year –7 (in mm)

RUNOFF 990 mm/year

Runoff in streams and rivers comes from precipitation, meltwater and groundwater. Only part of the precipitation runs off on the surface. The rest infiltrates the soil and groundwater or is stored as snow or glacier ice. This interim storage ensures that most rivers and streams carry water even at times when there is no precipitation. It is also responsible for characteristic seasonal fluctuations in runoff.

Climate change will alter seasonal runoff fluctuations:
Winter +59 | Spring +10 | Summer –116 | Autumn –38
Year –85 (in mm)

EVAPORATION 460 mm/year

As the link between the atmosphere and water bodies, the land surface plays a vital role in the water cycle. A third of all precipitation in Switzerland evaporates – from the soil, from water surfaces and via plants.

Climate change will intensify evaporation in all seasons:
Winter +16 | Spring +25 | Summer +2 | Autumn +6
Year +49 (in mm)

Lakes

Total volume 130 km³

Sustainably usable volume:
approx. 2 km³/year

Runoff in mm/year:

Annual total in millimetres of water for the reference period 1981–2010

Winter/Spring/Summer/Autumn/Year: Increase and decrease in millimetres of water per season or year for the period 2070–99 without climate change mitigation (RCP8.5) compared with the reference period.

The values in millimetres relate to hydrological Switzerland (Switzerland plus areas in neighbouring countries that drain into Switzerland). 10 millimetres of water column corresponds to a volume of 0.54 cubic kilometres, roughly equivalent to the volume of Lake Murten.

The figures in cubic kilometres refer to the area within Switzerland's borders, including the total volumes of the border lakes.

SUSTAINABLY USABLE VOLUME of all reservoirs 23.5 km³/year

The largest usable reservoir in Switzerland is groundwater. Natural and artificial lakes are also important. Humans use this water, but it is important that they only take what can be sustainably replenished. If too much water is extracted from lakes and groundwater, it may result in wetlands drying out or water levels in rivers falling too low. The water level of artificial reservoirs is managed, and almost the entire storage capacity can be used.

Climate change will affect the water levels in different types of reservoir over the course of the year.

Groundwater

Total volume 150 km³

Sustainably usable volume:
approx. 18 km³/year

SIGNS OF CLIMATE CHANGE

Average air temperatures in Switzerland have risen by around 2 °C since 1864. This measurable warming is affecting the water regime in a variety of ways.

Precipitation
Annual precipitation amounts in Switzerland have barely changed since records began in 1864. While winter precipitation has increased in many regions, summer precipitation has declined. So far, however, this seasonal trend is only statistically significant for winter precipitation in the Swiss Plateau and the Jura. Heavy precipitation has also become more frequent and intense since the start of the 20th century.

Snow
As a result of warmer temperatures, the winter zero-degree line has been rising for decades, and is now 400 metres higher than it was in 1960. That is why there is more rain and less snow in winter. At low altitudes (below 800 metres above sea level), the number of days with snowfall has halved since 1970. At altitudes above 2,000 metres, there has been a 20% decrease.

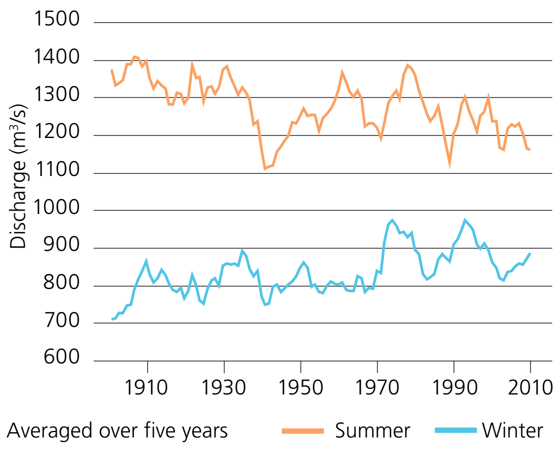
Runoff
Annual runoff amounts have hardly changed in the past 100 years. In many areas, however, winter runoff has increased and summer runoff has decreased.

Climate change is already having a significant impact on runoff and water resources.

Floods
Heavy rain causes streams and rivers to swell, leading to high-water levels and flooding. If heavy rain does not infiltrate the soil quickly enough, it can run off on the surface and cause flooding, even at some distance from water bodies. In the past, periods of frequent heavy precipitation and flood events in Switzerland alternated with periods when there were few such events. Since the 1970s, an increase in both the frequency and the intensity of flood events has been observed. Climate change is likely to be one of the reasons for this.

Low flow
Since 2000, Switzerland has experienced more and more dry periods lasting for several weeks, especially in summer. In 2018, for example, there was a third less rainfall between April and September than is normal for this time of year. Water levels in rivers, lakes and groundwater fell, and there were water shortages in some areas.

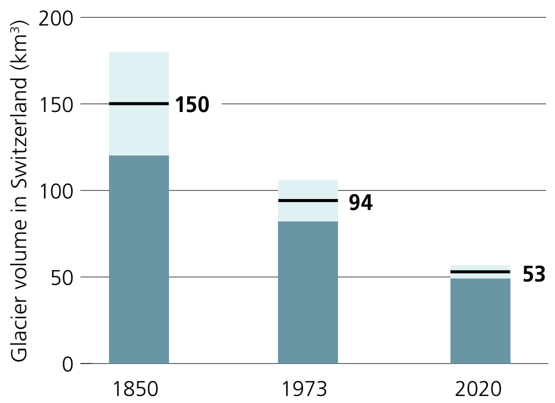
Discharge in the Rhine
The figure shows the discharge, averaged over five years, at the Basel gauging station. The summer and winter discharge patterns have reversed.



Glaciers
Glaciers have lost over half of their volume since 1850. As a result of increasing warming, significantly more glacier mass melts in the summer half-year than can accumulate in the winter. Moreover, the ice is melting earlier and earlier in the year.

Permafrost
At altitudes of over 2,500 metres above sea level, parts of the subsoil are frozen all year round. The ice content in the soil has reduced significantly as a result of the warming climate.

Glacier volume
The graph shows that the total ice volume of Swiss glaciers has decreased dramatically since 1850. The light areas indicate the uncertainty range.

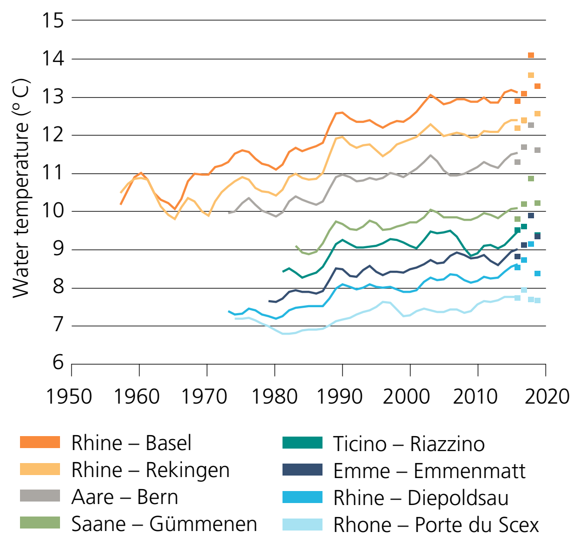


Source: Glacier Monitoring in Switzerland (GLAMOS)

Water temperature
Watercourses and lakes have become significantly warmer in recent decades. Mean water temperatures in Swiss rivers and streams have risen by more than 1 °C since 1970.

Groundwater
Shallow groundwater bodies have already warmed slightly in some places. During prolonged dry periods, the amount of groundwater available at some springs and pump wells has declined sharply. By contrast, deeper groundwater has barely been affected by climate change as yet.

Water temperature of rivers
Using a number of examples, the graph shows that the mean annual water temperature in Swiss watercourses has risen significantly in recent decades. Moving averages (over seven years) are shown as lines and the last four annual means are shown as points.



CHANGES IN RUNOFF

The contribution of meltwater from snow and ice to runoff will continue to decrease, leading to changes in the seasonal distribution of runoff. In the future, Swiss watercourses will carry more water in winter and less in summer, although the total annual runoff will only decrease slightly.

"Almost 60% of Switzerland's electricity comes from hydropower plants. In the future, run-of-river power plants on major rivers may be able to generate less electricity in summer, but more in winter. This is a good thing as energy consumption is particularly high in the winter. However, as the glaciers disappear and annual runoff decreases slightly, there will be less water overall for electricity generation."

Maja, power plant engineer

Climate change will affect the water balance in two ways: by altering the seasonal distribution of precipitation and by increasing the air temperature. The climate scenarios show that precipitation will increase in winter and decrease in summer, with evaporation increasing in all seasons.

In winter, warming means that more precipitation will fall as rain, even at higher altitudes, and therefore run off more quickly. A smaller area of Switzerland will be snow-covered. In addition, the snowpack will form later in the year and melt earlier. As a result, runoff and groundwater recharge will increase in the winter months, whereas there will be less meltwater in spring and summer.

In summer, higher temperatures will cause the glaciers to melt faster, meaning that the watercourses supplied by these glaciers will carry more water. However, this will only be a temporary phenomenon: meltwater from small glaciers is already starting to decrease again, with large glaciers expected to follow suit by 2050 at the latest.

The combined effect of all these developments is that, in the future, almost all watercourses will carry more water in winter. In the absence of climate change mitigation measures, winter runoff will increase by between 10 and 50% by the end of the century, while in summer and autumn it will decline by 30 to 50% compared with today.

The change in seasonal inflows will also affect water levels in lakes. However, total annual runoff will probably only decline by around 10%.

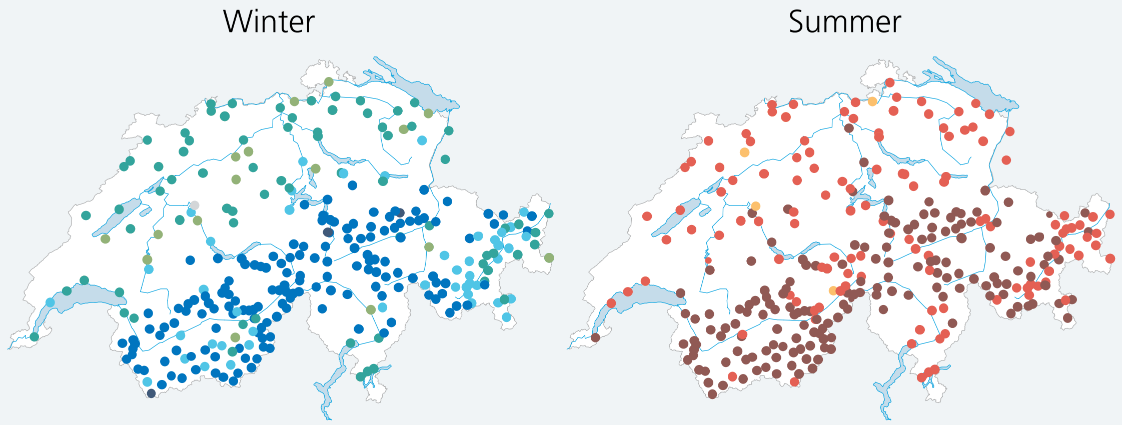
The seasonal dynamics of groundwater levels and spring discharge rates will also change, with high and low phases becoming more pronounced. Water levels and discharge rates will become higher in winter, and lower in summer. Water management practices must adapt to these changed conditions.

	With climate change mitigation end of the century	Without climate change mitigation end of the century
Runoff from snowmelt	–0 to –30 %	–30 to –60 %
Winter runoff	+0 to +20 %	+10 to +50 %
Annual runoff	–5 to +5 %	–0 to –20 %

Possible range of changes in 2070 to 2099 in comparison to 1981 to 2010 (simulation range).
30-year averages across Switzerland rounded to 5%.

Snow and glaciers will lose importance in Switzerland's water balance.

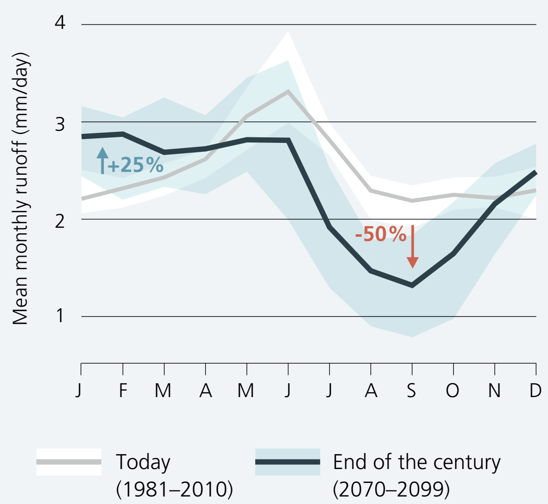
Expected changes in runoff
The maps show the expected changes in seasonal runoff for various catchments by the end of the century (2070–99) compared with the reference period (1981–2010) if no climate change mitigation takes place.



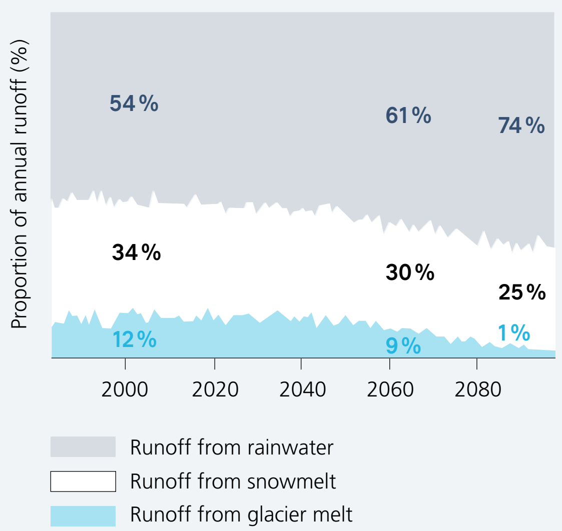
Deviation from the reference period in %

- Very significant decrease (–60 to –40)
- Significant decrease (–40 to –20)
- Slight decrease (–20 to –5)
- No change (–5 to 5)
- Slight increase (5 to 20)
- Significant increase (20 to 40
- Significant increase (40 to 60)
- Significant increase (>60)

Annual cycle of the Rhine
The arrows show how the mean monthly runoff of the Rhine at Basel will change by the end of this century if no climate change mitigation takes place. The lighter areas represent the simulation range.



Water in the Kander
The graph shows how the proportions of rainwater and meltwater from snow and glaciers in the runoff at Kandersteg will change if no climate change mitigation takes place. The proportion of rainwater increases significantly from 54 to 74%.



WATER SHORTAGES IN SUMMER

In the future, rivers and streams will carry less water in summer than they do today. Dry periods will also become longer and more frequent. During such extreme events, temporary water shortages may occur in some regions.

"Climate change is leading to more drought, which puts our harvests at risk. When temperatures are higher, the plants need more water to thrive, but I'm not allowed to irrigate more because water is scarce in our area in summer. In the future, I'll probably have to switch to varieties and crops that can better tolerate heat and drought. However, I already make sure that I switch to water-saving irrigation."

Simon, farmer

The hydrological scenarios show that, in general, water levels will drop significantly in summer and autumn. This applies to both surface waters and groundwater. All altitudes and regions will be affected by the decline, but especially the Alps and Alpine foothills. In the absence of climate change mitigation measures, summer runoff will be on average 30 to 50% lower than today by the end of the century, and up to 60% lower in present-day glacier streams.

At the same time, dry spells and heatwaves will become more frequent in summer and last for longer. Without climate change mitigation, summer low flow at altitudes below 1,500 metres will decrease by 30% during dry spells by the end of the century.

This increases the risk that springs, wetlands, streams and smaller rivers will dry up more frequently during periods of low rainfall. In addition, life in and around waters will be impacted more often by insufficient water depth and high temperatures. Some streams and rivers are likely to dry up completely during dry periods in the summer, especially small and medium-size watercourses and those in karst areas such as the Jura.

The amount of usable water will diminish in summer due to climate change. If, at the same time, more river water or groundwater is used for irrigating crops or for cooling purposes, this may trigger temporary regional water shortages. Already today, these two uses have to be restricted during dry spells in summer.

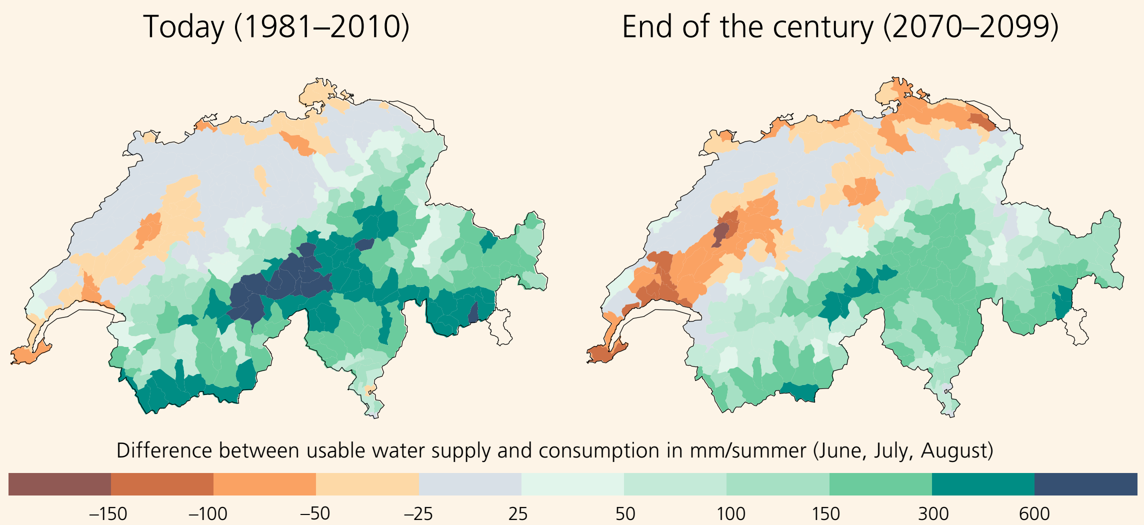
Until now, high-altitude Alpine streams and rivers have usually had low flow in winter, when the water is stored in snowpack. In the future, regions above 2,000 metres will see runoff increase when water levels are low in winter. At altitudes between 1,500 and 2,000 metres, climate change may shift the low flow season from wint er to summer and autumn. However, low flow rates will hardly change.

	With climate change mitigation end of the century	Without climate change mitigation end of the century
Low flow in areas below 1500 meters a.s.l.	–0 to –30 %	–10 to –50 %
Summer runoff	–0 to –20 %	–30 to –50 %

Possible range of changes in 2070 to 2099 in comparison to 1981 to 2010 (simulation range).
30-year averages across Switzerland rounded to 5%.

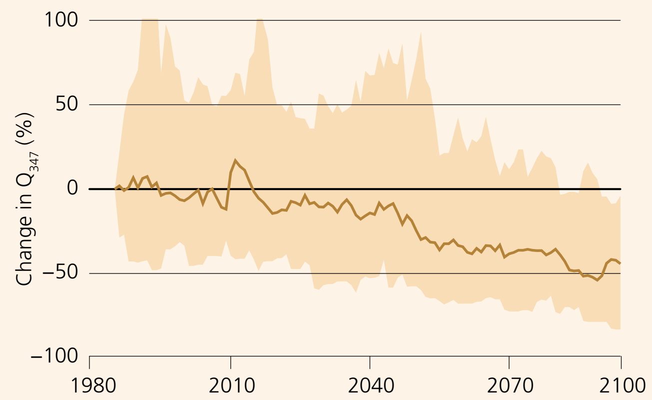
Drought in summer and autumn will lead to more water scarcity in some regions.

Balance between water supply and consumption
The maps show the difference between usable water supply and consumption in the summer of a year with little precipitation, today and at the end of the century, assuming no climate change mitigation takes place. Water shortages occur in catchments coloured orange/brown. In these catchments, the demand for water in summer exceeds the usable resources in streams, rivers and lakes. Some regions are already experiencing water shortages in dry years, and these are set to become more pronounced in the future.



Low flow in the Thur
Using the example of the River Thur at Halden (canton of Thurgau), the figure shows how low flow discharge rate could change without climate change mitigation. The value Q_{347} represents the discharge that the river exceeds on average on 347 days a year.

Low flow in areas below 1,500 metres will thus be significantly lower in the future than they are today. The light area represents the simulation range.



GROWING HAZARD POTENTIAL

More intense heavy rainfall will lead to more localised flooding and surface runoff. There is also evidence to suggest that large-scale floods will become more common. In addition, warming will cause glaciers to melt and will destabilise the frozen subsoil in high-altitude areas.

"We have to be prepared for an increase in damage caused by surface runoff from heavy rainfall. Many buildings in Switzerland are at risk. Anyone who owns a property should definitely check the surface runoff risk map to see whether the property is in an at-risk area. Even simple measures can prevent water from entering underground garages or basements, for example."

Renato, firefighter

A warmer atmosphere will contain more energy and be able to absorb more moisture, increasing the potential for heavy rain and thunderstorms. The heaviest single-day precipitation events will therefore be 20% more intense by the end of the century unless climate change mitigation is implemented. This means that a future summer thunderstorm may release considerably more rain than its equivalent today. Heavy precipitation events will also become more frequent.

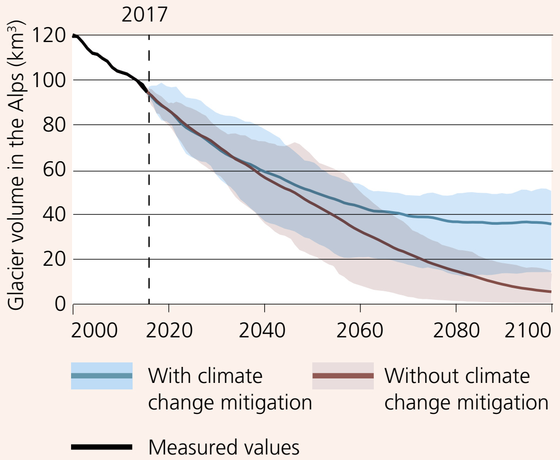
As a result, localised flooding due to floods and surface runoff will increase. During surface runoff precipitation does not infiltrate the soil but inundates open ground, causing damage to buildings, infrastructure and fields. Two thirds of all buildings in Switzerland are located in areas potentially at risk from surface runoff.

There is also evidence that floods due to prolonged precipitation may become more frequent and cause widespread flooding and damage. Despite a definite increase in localised heavy precipitation, the future development of rare large-scale flood events remains difficult to predict.

As rising temperatures thaw the permanently frozen subsoil (permafrost) in the mountains and cause glaciers to shrink, slope stability in the mountains will diminish. Landslides, rockfalls and debris flows will become more common, while the volume of loose rock and debris will increase. During flood events, the loose material will be transported to lower areas, where it can cause damage.

Glaciers are melting

The graph shows how the volume of glaciers in the Alps will change in the future. The light areas indicate the range of the simulations.



Source: Zekollari et al. 2019

As the population grows and the landscape is used more intensively, more and more assets and property will be at risk from natural hazards. To prevent damage, a natural hazard map and a surface runoff risk map are available (www.bafu.admin.ch/natural-hazards). These show the areas at risk from adverse events.

Integrated risk management has proved an effective way of dealing with risks from natural hazards in Switzerland. This comprehensive approach will also allow those responsible to take systematic account of the changes brought about by climate change – for example when drawing up land use plans, building regulations or emergency response plans.

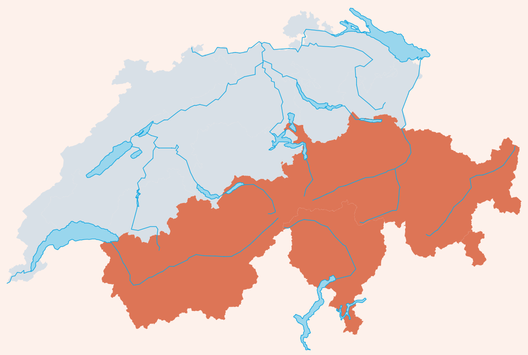
	With climate change mitigation end of the century	Without climate change mitigation end of the century
100-year single-day precipitation event	+5 %	+20 %
Glacier volume Alps	–50 to –80 %	–90 to –100 %

Possible range of changes 2070–2099 compared to 1981–2010. 30-year averages across Switzerland rounded to 5%.
Uncertainty range of heavy precipitation is not considered, since it is strongly determined by natural fluctuations.

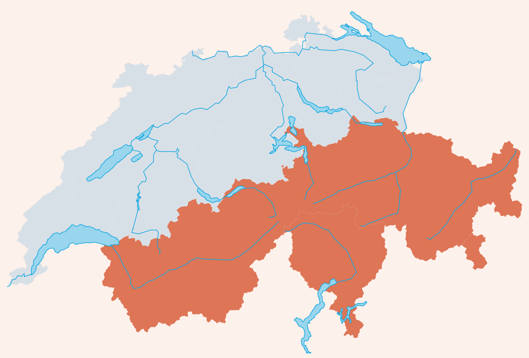
Factors influencing high-water events and how climate change will affect them

More energy and moisture in the atmosphere
- Increase in frequency and intensity of heavy precipitation
- Increase in surface runoff
- More local high water and flooding

Changes in atmospheric circulation
- Continued high natural variability
- Increase in large-scale flooding possible due to prolonged heavy precipitation
- No definite prognoses yet available



Higher zero-degree line
- More precipitation in form of rain
- Longer flood season



Greater availability of loose material
- Increased hazard from rocks and scree
- More sediment transport in Alpine watercourses

Spatial impact on floods
- Increase expected
- No change

Natural hazards such as high-water levels, flooding and landslides will increase.

AQUATIC LIFE AT RISK

Intensive use and hard engineering of water bodies as well as pollutant input are affecting many animals and plants that live in and around water. Climate change is placing added pressure on the water bodies due to higher water temperatures and changes in runoff. This will lead to a decline in biodiversity in and around water bodies.

"Trout prefer water temperatures of around 13 °C. Above 20 °C they get stressed, and over 25 °C the fish will only survive for a short time, meaning that large populations are at acute risk. But climate change isn't just a threat to trout. Other animals that are adapted to cool and oxygen-rich waters will regionally die out, in some cases completely unnoticed."

Aline, biologist

Rivers and streams in all parts of Switzerland will continue to get warmer. If global greenhouse gas emissions continue as before, summer water temperatures in watercourses could rise by 3 to 9 °C by the end of this century. However, if climate change mitigation measures are implemented, warming in summer is likely to remain below 3 °C compared with present levels. In winter, the warming will be less pronounced.

Climate change will also result in more low flow periods in summer, with streams and river sections drying up more and more frequently. The combined effect of warming and water scarcity is likely to lead very quickly to major changes in ecosystems.

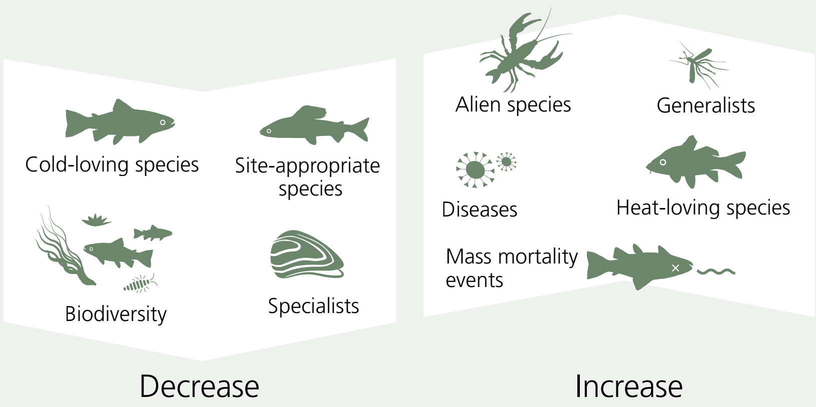
The annual average water temperature on the surface of lakes could increase by 3 to 4 °C by the end of the century due to climate change. This will hinder the exchange between surface and deep water. As a result, the distribution of oxygen and nutrients in lakes will alter, which will have consequences for the entire food web.

Some aquatic organisms will be able to adapt to climate-related changes by moving to cooler waters, mostly at higher elevations. However, this will only be possible if there are no obstacles in their way, such as hydropower plants or weirs. Moreover, the new environment must be suitable for them. For example, the temperature of mountain streams would be ideal for grayling, but this species would be unable to cope with the strong currents.

The risk to diversity extends beyond fish and crustaceans, which are already among the most threatened species in Switzerland. All native biodiversity in and around water is already under severe pressure. Climate change is adding to this pressure. In addition, the changed conditions will allow invasive, alien species to settle and spread even more successfully.

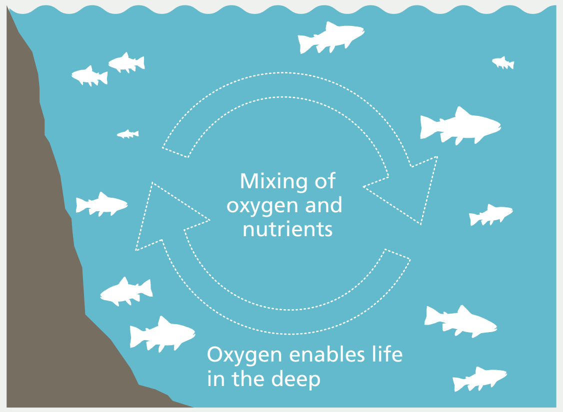
	With climate change mitigation end of the century	**Without climate change mitigation** end of the century
Water temperature streams summer	+1.5 to +3 °C	+3 to +9 °C
Annual lake water surface temperature ual	ca. +1 °C	+3 to +4 °C

Possible range of changes 2081–2090 relative to 1991–2000 for streams and 2070–2099 relative to 1981–2010 for lakes.
10- and 30-year averages across Switzerland rounded to 0.5 degrees.

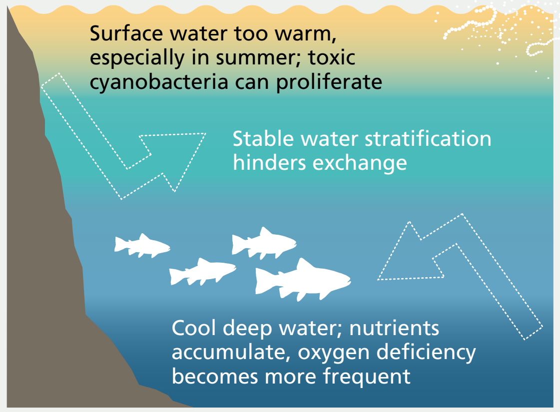


Winners and losers
Aquatic life will respond to climate change in different ways. While some organisms will benefit from the changed conditions, others will cope poorly or not at all. Overall, there will be a reduction in native biodiversity.

Effects of global warming on lakes
The illustrations show how climate change affects natural processes in lakes.

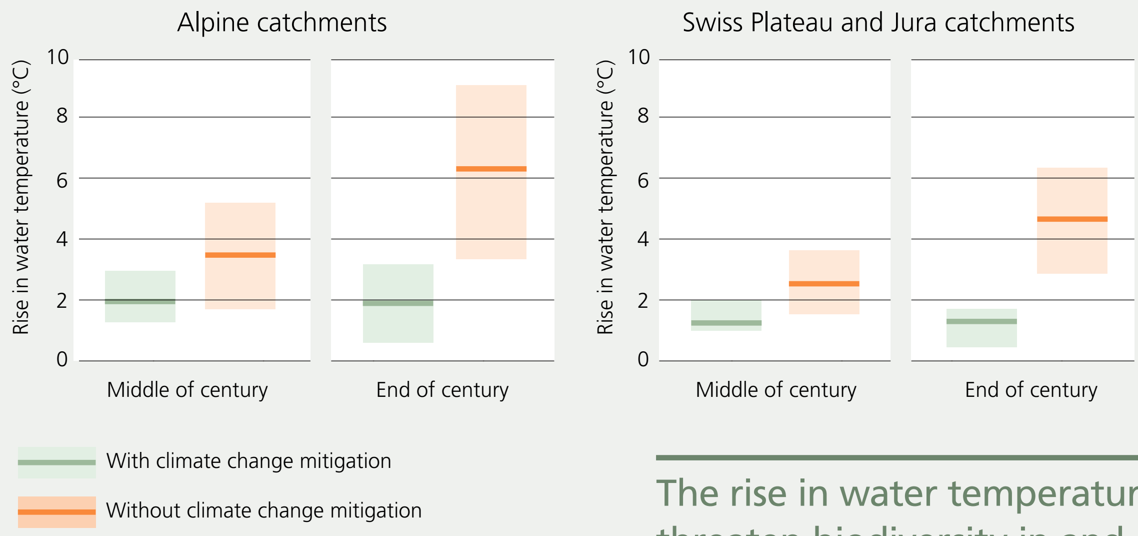


Today, most Swiss lakes mix completely once a year in winter or twice a year in spring and autumn ('turnover').



Climate change could result in less frequent turnover in some lakes in the future. For all lakes, the duration of stable stratification will increase in summer and water temperatures will rise.

Water temperatures in watercourses
The two graphs show the expected development of the average temperatures of Swiss watercourses in summer.
The light areas indicate the simulation range.



The rise in water temperatures will threaten biodiversity in and around water bodies.

RESPECTING LIMITS ON USE

Climate change has major implications for the use of water bodies by humans. Drinking water abstraction, irrigation, electricity generation, heat production and cooling will be limited at times, and there will need to be trade-offs between different uses in order not to overload ecosystems.

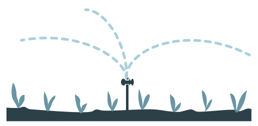
Drinking water supply

Four fifths of Switzerland's drinking water comes from groundwater. The input of pollutants from agriculture and settlements into groundwater is therefore a major problem for drinking water supplies, especially in intensively used and densely populated areas.

Climate change will result in longer dry periods, especially in summer and autumn. Drinking water suppliers must therefore be prepared for the output of some pump wells and springs to be reduced at this time of year, bearing in mind also that pollutant concentrations in water are liable to increase at these times due to lower dilution.

One important adaptation measure will be for every supply system to draw its water from at least two independent areas of origin, such as a lake and a groundwater body, and to be connected to neighbouring supplies. Such precautions will prevent Switzerland from facing drinking water shortages in the future.

Other water uses must neither impair nor compete with drinking water resources. These include water abstraction for cooling or heating buildings, for industrial processes or for irrigation. Groundwater must also be better protected from potential pollution, especially from agriculture.



Irrigation

Until now, precipitation in Switzerland has usually been sufficient to meet the water demand of most agricultural crops. However, summer precipitation is set to decline as a result of climate change, and as temperatures rise, more moisture will evaporate from the soil, so that plants will need more water.

Crops that are already irrigated today will need around twice as much water by the end of the century unless effective climate change mitigation measures are implemented. However, during hot, dry periods, many rivers and smaller groundwater bodies already have very little water to spare for irrigation.

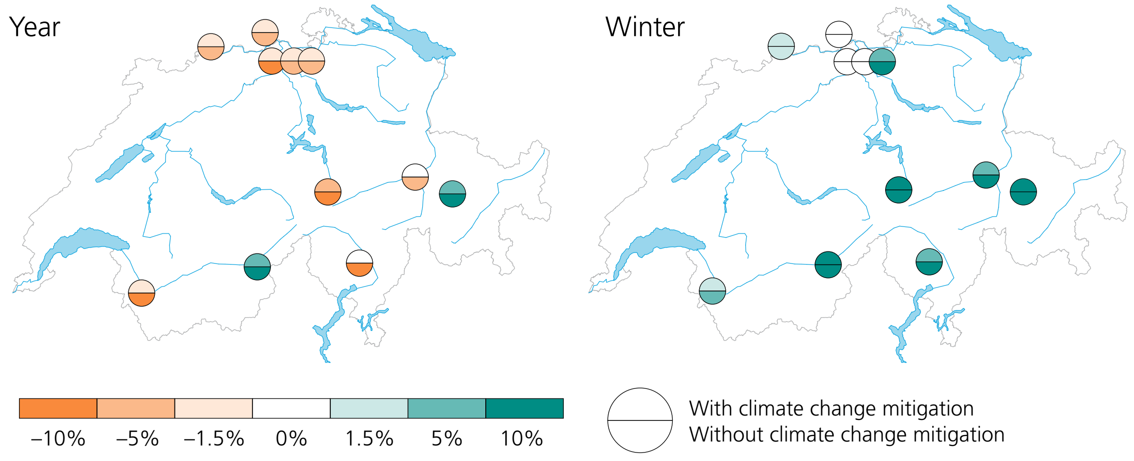
As site-adapted agriculture is the ultimate objective, farms will have to adjust to the changing conditions in the medium term. This will mean factoring in other climate-related risks such as heat stress, increased pest pressure, heavy precipitation events and hail. Agricultural cultivation methods, products and sites will need to be completely reappraised. A move to growing drought-resistant species or varieties is unavoidable.

With new irrigation infrastructure currently being planned and built in many crop-growing areas, expanding water-inefficient irrigation systems and intensifying agriculture (more vegetable growing, for example) will not be compatible with the increasing scarcity of water supplies in the future. Regional resource planning will also be necessary to prevent the overexploitation of water resources. In addition, a transparent presentation of water costs would be useful to avoid creating misplaced economic incentives.

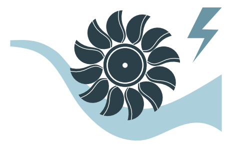
Climate change will require regional water resource planning and a reappraisal of all water uses.

Production at hydropower plants

The figure shows examples of 11 run-of-river power plants in Switzerland, indicating how electricity production will change by the end of the century with current plant configurations and residual flows. It can be seen that the plants will generate more power in winter, but less in summer and over the year as a whole.



Source: SCCER-SoE 2019



Hydropower

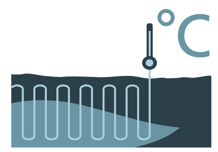
The usable hydropower potential in Switzerland has been largely exploited. Hydropower generates 60% of Switzerland's electricity and, being a renewable resource, is an important contributor to the energy transition. It supports the decarbonisation of Switzerland's energy system. However, the use of hydropower also has an ecological impact on waters. The necessary conservation and expansion of hydropower must therefore be carried out in such a way that it has the least possible impact on river ecosystems. Any expansion should focus on optimising existing facilities and be carried out in such a way that the few remaining intact water bodies are preserved.

Hydropower itself will also be affected by climate change. Although the Alpine reservoirs will continue to fill up, meaning that their storage capacity can largely cushion the seasonal changes in inflows, the way they are managed will need to change.

In the case of reservoirs with heavily glaciated catchments, the amount of water available will decrease in the long term as the glaciers disappear. At the same time, the influx of loose material will increase. Countermeasures will therefore be required to prevent the deposits from reducing the storage capacity.

The output of run-of-river power plants is directly linked to the runoff. With summer runoff expected to decline, these plants will be able to generate less electricity during the warm months. In winter, however, when energy demand is high, the rivers will carry more water, meaning that more power can be produced.

Provided measures are taken to mitigate climate change, annual electricity production from hydropower will barely change in the long term, decreasing only slightly if at all. Without climate change mitigation, though, the amount of energy generated could fall by up to 7% by the end of the century.



Thermal use

Water bodies can absorb energy very effectively in the form of heat and then release it again. That is why, for decades, watercourses have played an important role in cooling large installations. Groundwater is also used intensively for cooling and heating purposes in many regions.

In summer, watercourses are increasingly reaching temperatures that affect the organisms living in the water. Consequently, using cooling water from rivers in a way that heats up the water even more will scarcely be possible in the future. However, it will still be possible to use water from larger lakes thanks to their substantial volume. To avoid negative impacts on ecosystems, abstraction systems and return lines must be designed in such a way that they do not alter the stratification conditions in the lake.

Tourism

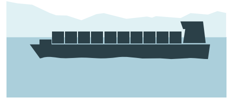
The warming climate is becoming an even greater challenge for winter tourism. Most resorts use snowmaking machines to make up for the decline in snowfall. In 2016, half of Switzerland's approximately 22,500 hectares of ski slopes were covered with artificial snow. However, snowmaking uses a lot of water, which is usually not naturally available at high altitudes in autumn and winter.

Cable car companies are increasingly building storage basins for meltwater and rainwater, which can affect the quality of the landscape. In many places water for snowmaking has to be pumped up from lower elevations, which is extremely energy-intensive. Some lower-lying winter resorts have already closed down because artificial snowmaking is not economically viable or because the temperatures are too warm. Others are sure to follow.

The melting of the glaciers will change the appearance of the landscape. This will particularly affect destinations that currently rely on glaciers and associated attractions to draw in visitors. How attractive the high-mountain landscapes will be to holidaymakers once the glaciers have gone remains to be seen.

However, climate change will also open up opportunities for tourist regions in the mountains if more people want to escape the heat in urban areas. In addition, the summer season will last for longer as the first snowfall will start later and later in the year. Overall, rivers and lakes are likely to become even more important for recreation and tourism in the future, luring visitors with the chance to cool off during the summer heat.

As Swiss water resources become even more important for neighbouring countries, greater international cooperation will be needed to manage them.



International cooperation

Switzerland's neighbouring countries use the water that flows across its borders. For decades, international agreements, treaties and bodies have been governing cooperation in this area and setting objectives for transboundary waters.

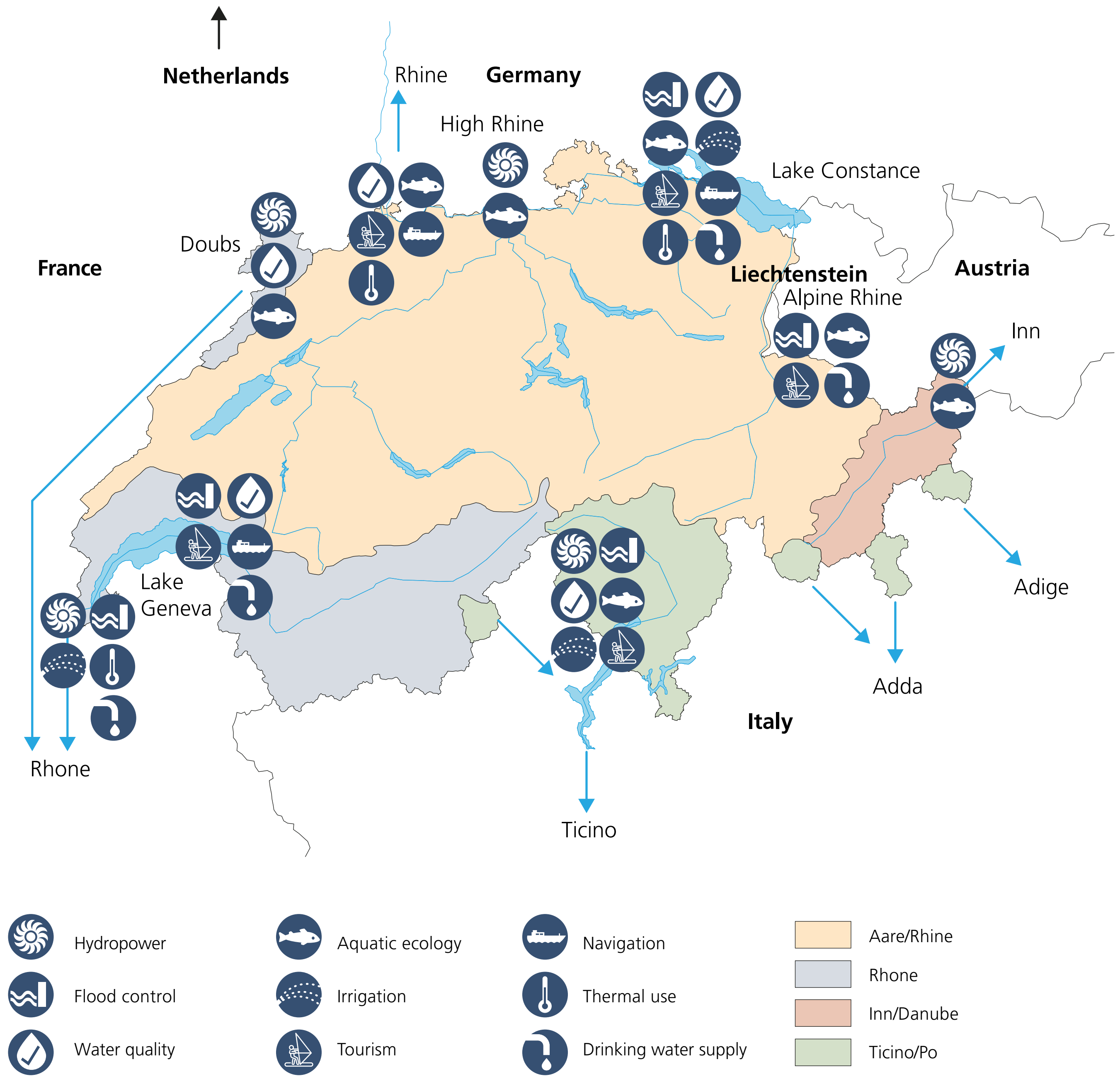
The impacts of climate change in Switzerland will also be felt by countries further downstream. For example, low flow events are expected to become more frequent in the Rhine below Basel, which will cause problems with water supply, irrigation and even reductions in hydropower production in Germany, France and the Netherlands.

But low water levels in the Lower and Middle Rhine will also have implications for Switzerland, especially its economy. Over 10% of Switzerland's foreign trade volume – around 7 million tonnes of goods each year – is transported on the river. Low water levels mean that ships cannot carry as much cargo, and may even be unable to sail at all.

An example of conflicting cross-border objectives can be seen at Lake Maggiore. The Italian regions of Lombardy and Piedmont request that the lake should be as full as possible in summer, so that it can be used to supply water for irrigation. By contrast, the towns and villages on the shores of the lake, on both the Swiss and Italian sides, want to regulate the water to a lower level so that the lake can cope with high summer water levels without bursting its banks.

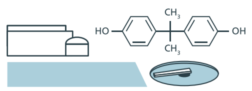
Adapting to climate change will therefore also require sustainable and consensual management of rivers and lakes across national borders. On the one hand, this entails making further improvements to water quality, for example by deploying the latest sewage treatment technologies and taking measures in the agricultural sector. But just as important is the cross-border coordination of water management. Here too, many conflicts can be avoided by using water efficiently and focusing on those uses that are most important for society.

Cross-border cooperation
The map shows the main surface water bodies and catchments in Switzerland.
Symbols indicate which uses and aspects of the waters are regulated by cross-border cooperation.



MAKING WATER BODIES MORE RESILIENT TO CHANGE

Ecologically intact water bodies will be better able to cope with climate change and meet the diverse demands of society. It is therefore important to protect water resources from excessive abstraction and from contamination by pollutants and fertilisers. In addition, streams, rivers, lakes and groundwater must be kept in, or restored to, a state that is as natural as possible.



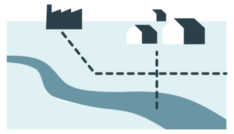
Protecting against contamination

An extensive network of sewers collect over 97% of Switzerland's municipal waste water. This is treated at around 800 waste-water treatment plants (WWTPs) and then discharged into rivers or lakes. With climate change, this tried-and-tested system will reach its limits: if low water flows in rivers mean that the effluent from WWTPs is less diluted, releasing even treated waste water will cause too much pollution in water bodies.

It is therefore important that the volume of pollutants from settlements entering water bodies is lowered still further. To reduce the chemical pollution of rivers receiving a high proportion of waste water, by 2040 approximately 140 strategically chosen WWTPs are to be adapted to include additional treatment stages.

Intense rainfall events are set to increase. These events result in so much water flowing into the sewer system that WWTPs can no longer process it, meaning that some untreated waste water ends up in rivers. To avoid this, steps should be taken in the future to prevent as much rainwater as possible from sealed surfaces from entering the sewer system. Instead, there must be more systematic attempts to infiltrate or retain it within settlements. Such measures could also help to mitigate the growing problem of heat stress in cities.

Another challenge facing water bodies is the input of pollutants from agriculture: residues of pesticides and fertilisers end up in groundwater, rivers and lakes, affecting drinking water supply and aquatic ecology in many places. The increase in heavy precipitation will enhance the runoff of nutrients and pollutants from fields into waters, and higher levels of winter precipitation will transport more nitrate from fertilisers into groundwater. It is therefore vital to reduce the amount of pollutants being applied. This is the aim of the federal government's Plant Protection Products Action Plan launched in 2017.

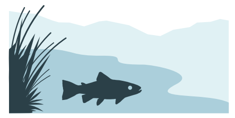


Preventing overuse

Water abstractions for settlements, industry/commerce and agriculture are widespread in Switzerland, targeting groundwater as well as rivers and lakes. By far the most significant in terms of quantity are the approximately 1,500 abstractions by hydropower plants. The Waters Protection Act regulates how much water must remain in bodies of water below the point of withdrawal, thus preventing them from partially or completely drying up.

Wetlands, as well as many streams and rivers, require sufficiently high groundwater levels to prevent them from drying out or running too low during a drought. Economical use of groundwater abstraction is therefore a necessity.

For water bodies to be able to adapt to climate change, their natural functions must be strengthened.



Aiming for a near-natural state

In Switzerland, obstacles in watercourses considerably limit the mobility of numerous aquatic organisms. Hydropower plants and weirs, for example, hinder or entirely prevent the migration of fish and other animals such as crayfish.

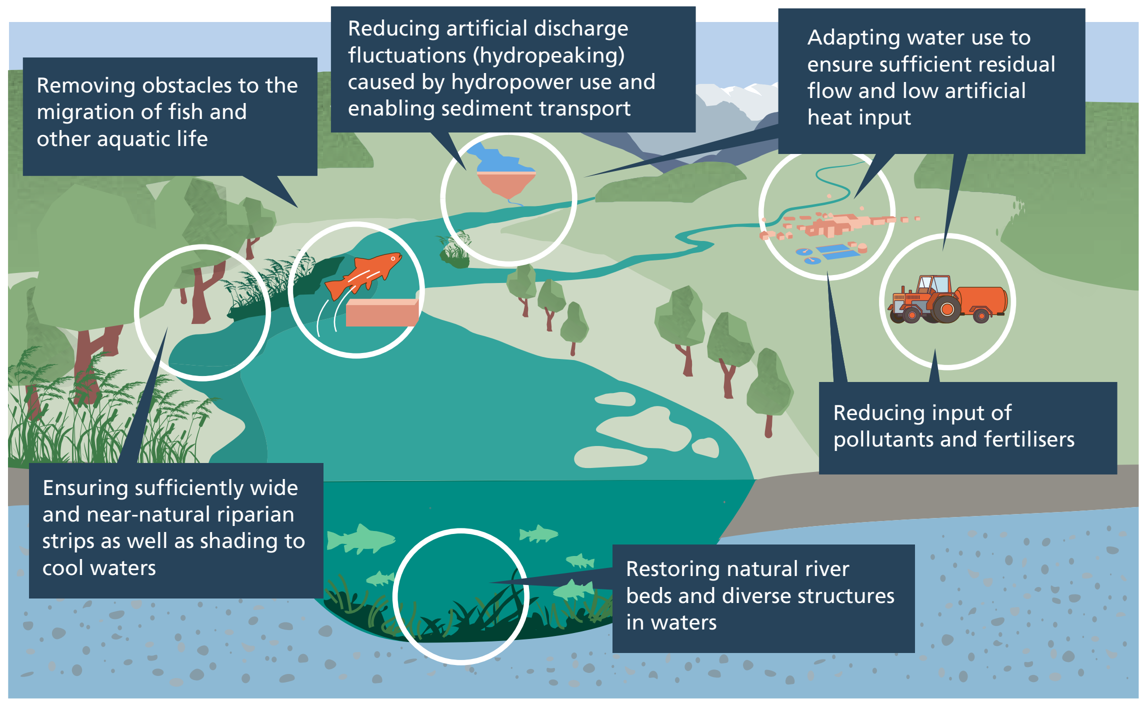
In the 20th century, many watercourses were straightened and structurally engineered to protect against flooding. In addition, most of Switzerland's wetlands have been drained to create land. Some 16,000 kilometres – around a quarter of all the country's watercourses – have now been structurally impaired or even channelled into underground pipes.

As part of the 2011 revised Waters Protection Act, Switzerland launched two long-term projects to rehabilitate watercourses:

By 2030, fish migration is to be improved at some 1,000 weirs, excessive discharge fluctuations (hydropeaking) will be eliminated at around 100 hydropower plants and 500 installations with bedload deficits will be remediated. In addition, work has begun throughout the country to restore more space and naturalness to some 4,000 kilometres of watercourses by 2090 and to provide better shading.

Ecological restoration and renaturation will make aquatic life more resilient to climate change, and will also help to enhance wildlife connectivity and the beauty of the landscape. However, climate change mitigation measures are just as important in order to keep the rise in water temperatures and changes in runoff as small as possible.

Measures to strengthen surface water bodies
Near-natural watercourses are better able to cope with the challenges of climate change than those that have been heavily modified by humans. The implementation of waters protection measures will therefore become even more important.
A range of measures are needed to promote near-natural watercourses, such as:



A LOOK BEHIND THE SCENARIOS

The Hydro-CH2018 hydrological scenarios are based on model calculations by leading Swiss research institutions and take into account the latest climate scenarios.

To enable Switzerland to adapt to climate change, detailed knowledge is needed of how climate change will affect water bodies and the water balance. The Federal Council therefore commissioned the Federal Office for the Environment to supply the hydrological bases on which to base adaptation measures.

The Federal Council's mandate was implemented as part of the 'Hydrological principles of climate change' (Hydro-CH2018) priority theme at the National Centre for Climate Services (NCCS). The NCCS is the Swiss federal network for climate services. Hydro-CH2018 comprises 11 research projects as well as literature studies, and involved leading Swiss institutions specialising in water research (see page 26).

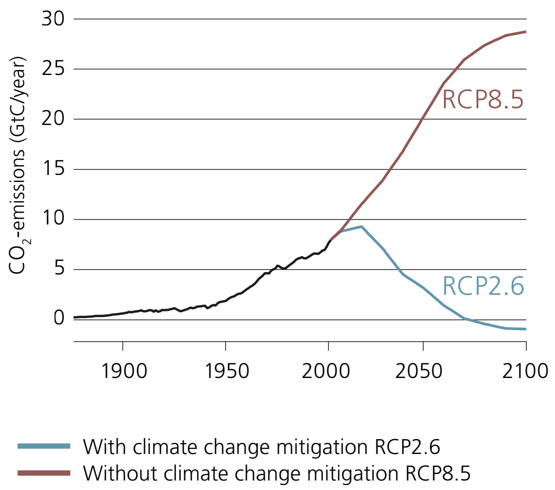
Compared with previous studies on the impacts of climate change on hydrology, Hydro-CH2018 was able to draw on improved data sets and methods. It is underpinned by the high-resolution CH2018 climate scenarios, which for the first time provide continuous daily data on a local scale for the years 1981 to 2099.

Hydrological scenarios

The hydrological scenarios are part of a 'model chain' that starts with multiple emission scenarios representing the possible future courses of greenhouse gas emissions and ends with models that calculate the impacts on water management or agriculture.

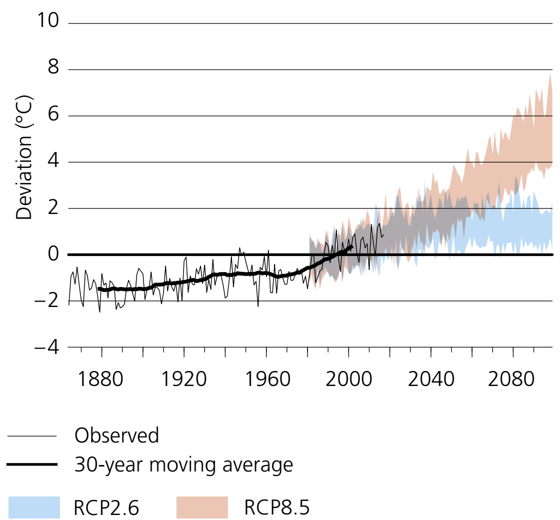
The CH2018 climate scenarios were developed by combining the emission scenarios with global and regional climate models. The hydrological models in turn use the results of the climate scenarios to calculate the hydrological scenarios, which show how Switzerland's water balance and water bodies will change. Hydro-CH2018 takes into account all key hydrological components such as runoff and groundwater recharge, glacier and snow melt, evaporation and water temperatures.

Emission scenarios
The curves show the expected course of global CO_2-emissions according to the two exemplary scenarios "Without climate change mitigation" (RCP8.5) and "With climate change mitigation" (RCP2.6).



Source: Adapted from IPCC 2013/WGI/Box 1.1/Figure 3b

Atmospheric warming
The graph shows the course to date (solid line) and the modelled future values (coloured areas) of the ground-level air temperature in Switzerland. The expected deviations from the annual mean temperature in the reference period 1981–2010 are shown.



Source: Climate scenarios CH2018 (NCCS, 2018)

Climate change mitigation measures

To illustrate the effectiveness of international climate change mitigation measures and show the range of possible future changes, Hydro-CH2018 examines the consequences of two representative emission pathways: 'With climate change mitigation' (RCP2.6) and 'Without climate change mitigation' (RCP8.5). RCP (Representative Concentration Pathway) is an internationally used abbreviation for globally defined emission pathways.

'With climate change mitigation' (RCP2.6) represents a future in which the international community implements effective climate change mitigation measures in accordance with the Paris Agreement. A drastic reduction in emissions will halt the increase in greenhouse gas concentration in the atmosphere within around 20 years. 'Without climate change mitigation' (RCP8.5) represents a future without effective climate change mitigation measures, in which global greenhouse gas emissions continue to rise sharply.

Uncertainties

Thanks to state-of-the-art computer models and mainframe computers, it is possible to create a mathematical model of the processes taking place in nature and to simulate their future development. This method was also used for CH2018 and Hydro-CH2018.

Assumptions have to be made for each calculation step, concerning, for example, how and to what degree of accuracy the processes are considered and calculated. These assumptions, which are largely dependent on data availability, are subject to uncertainties that propagate through the model chain.

To determine uncertainties in the modelling, models from different universities and research institutes are compared. In this way, differences between the models and the assumptions applied can be identified. This allows the results to be reviewed and checked for plausibility, and their accuracy estimated.

Terms and definitions

The area studied by Hydro-CH2018 includes the whole of Switzerland, Liechtenstein and other neighbouring regions that drain into Swiss territory – collectively referred to as 'hydrological Switzerland' by experts.

When the text refers to the current state ('today'), the mean hydrological state during the reference period from 1981 to 2010 is meant. These three decades were the starting point for calculating the scenarios. All information on future changes is in relation to this period.

The scenarios describe expected mean values and the range of possible changes in hydrological events over periods of 30 years. The terms 'end of this century' or '2085' describe the period from 2070 to 2099, 'middle of century' or '2060' the period from 2045 to 2074.

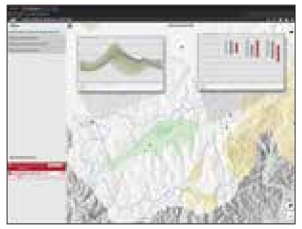
The hydrological conditions in individual future years cannot be determined from the mean values for the 30-year periods. Annual values may deviate greatly from the mean conditions due to natural variability.

There is no doubt about the nature and direction of the climatic and hydrological changes. However, their exact extent is subject to uncertainties.

MORE INFORMATION ABOUT HYDRO-CH2018

The NCCS web plattform
Containing general information on climate change, measures and climate scenarios. Central point of access for all Hydro-CH2018 products and publications.
www.nccs.admin.ch

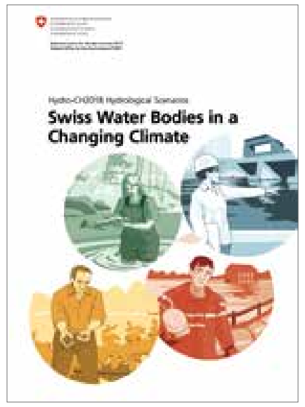
Scientific synthesis report
Effects of climate change on Swiss water bodies. Hydrology, water ecology and water management. Federal Office for the Environment FOEN, Bern. Environmental Studies No. 2101: 132 p.
www.nccs.admin.ch/hydro_en



Hydrological Atlas of Switzerland
Access to data, graphs, maps and indicators in the Hydrological Atlas of Switzerland. Data also accessible via the federal map portal.
www.hydromapscc.ch
www.map.geo.admin.ch

NCCS BROCHURES

NCCS (Hrsg.) 2018:
CH2018–Climate Scenarios for Switzerland
National Centre for Climate Services, Zurich. 24 pp.
978-3-9525031-3-3.



NCCS (Hrsg.) 2021:
Swiss Water Bodies in a Changing Climate
National Centre for Climate Services, Zurich. 28 pp.
ISBN 978-3-9525413-0-2.

RESEARCH INSTITUTIONS INVOLVED IN HYDRO-CH2018

Agroscope
University of Freiburg, Germany
Eawag – Swiss Federal Institute of Aquatic Science and Technology
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)
Swiss Federal Institute of Technology Lausanne (EPFL)
Swiss Federal Institute of Technology Zurich (ETHZ)
University of Applied Sciences Rapperswil (HSR)
Swiss Institute for Speleology and Karst Studies (SISKA)
University of Basel
University of Bern
University of Fribourg
University of Geneva
University of Lausanne
University of Neuchâtel
University of Zurich

Switzerland enjoys a great abundance of water. But the water bodies have been impaired for more than a hundred years – by water abstraction, chemical pollution and construction. For some time now, another problem has been increasingly noticeable: climate change. This brochure explains the water regime in Switzerland and describes the changes that can be expected.