Water management

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1. Introduction

Background

Water management includes all human activities related to water use, water protection and protection against water risks. Climate change affects these aspects of water management through changes in the water cycle (see Background chapter).

In the following chapter, the effects of climate change on the water cycle are discussed in detail for the following areas:

- Changes in natural waterbodies (lakes, biodiversity, fish)
- Water-related natural hazards (floods, drought)
- Water resources and water demand (groundwater recharge, demand for drinking and industrial water)
- Water utilisation (energy, Rhine shipping)
- Management of water resources

Climate change also influences other aspects of water management, such as inland shipping, the recreational value of water and water use in the production of goods. Although these and other topics are also important, they will not be covered here.

Water management is not only affected by climate change but in particular by human activities. In the past, population pressure, changes in land use, water use and water pollution were the relevant factors that led to continuously changing water management. As a result of climate change, not only the changes in water management need to be considered but now also changes in water resources. It is not clear whether changes in water resources or use will be more important in the future. In the worst case, the developments will go in opposite directions (decrease in supply and increase in demand).

Overview

Low water levels

In comparison to other regions of the world, Switzerland is in a favourable situation today, with about 5560 m^3 water available per year and per inhabitant (Israel 115, the Netherlands 690, Germany 1305, Spain 2785 m^3 a^{-1} E^{-1}). Abundant precipitation, as well as the balancing effect of snow cover and – to a decreasing degree – glacier melt, will also ensure a comparably rich water supply in the future.

As a result of climate change, the water supply in summer and autumn will decrease (see Background chapter). In particular, during the more frequent heat-wave summers even medium and larger midland rivers may have water levels as low as in winter. Accordingly, groundwater levels in valley gravels will decline more strongly in late summer and autumn.

At the same time, the agricultural demand for irrigation water will increase. As a result, competition will rise between the water demand of river ecosystems and different users and regions, in particular in the use of groundwater, and small and medium rivers. This competitive situation has different results:

- In agriculture, there may be production losses due to water shortage.
- Electricity production will be affected by reduced water supply and increased water temperatures (hydropower, withdrawal of cooling water).
- In Rhine shipping, limitations are expected in summer and autumn.

Floods

The damage potential of floods has increased considerably within the last 50 years. The reason for this is population and economic growth; valuable infrastructure is increasingly in exposed positions. This development will continue in the future.

Today's climate scenarios show an increase in mean precipitation, and in the frequency and intensity of intense precipitation in the winter half of the year. In addition, precipitation will fall more frequently as rain instead of snow. Due to these changes, an increase in flood frequency, particularly in winter, can be expected and may lead to higher flood water levels, primarily in the midlands and the Jura, as well as in the foothills of the Alps below about 1500 m a.s.l. For summer, no clear statements are possible so far.

The expected increase in damage potential, as well as the possibility of more frequent floods, requires greater protection against floods. A possible answer to these uncertainties are so-called “no-regret” measures, such as, for instance, sustainable flood protection: In the case of unchanged flood intensity, renatured and broadened rivers are a plus for river ecosystems; in the case of an increase in flood intensity as a result of climate change, the higher risk will be at least partly compensated for and minimised through the allowance for overload.

Ecology

The increase in water temperatures will also have unexpected effects on aquatic ecosystems, which, however, cannot yet be assessed.
In lakes, the warming will lead to a more stable concentration stratification and to a decrease in oxygen content in the deep water. This will increase the risk of oxygen deficiency in mesotrophic and maybe also in oligotrophic lakes.

Measures

Regional/superregional management of resources lends itself as a measure against water shortage. This requires a change in thinking in the direction of integrated water management of entire river catchments.
Lake management results in a reduction of and a shift in fluctuations. In the future, existing regulating schemata will need to be adapted to changed conditions (new target functions and optimisation). In the future, pressure will increase to manage lakes that are not regulated today. It is unclear what ecologic problems this entails. Effects on riverine vegetation are to be expected, for instance, on reed population and other vegetation communities that depend on the natural fluctuations of the water line.
The flexible floods strategy in Switzerland comprises measures in city and regional planning to limit the damage potential, property protection to reduce vulnerability, constructional protection measures and emergency measures in case of overload. The strategy proved its value during the flood of August 2005. Wherever the strategy had already been implemented, the damages were significantly reduced in comparison to similar floods. Regular examination of the risk situation is a prerequisite to implementing the strategy effectively in the long term, since both damage and danger potential change continuously.
In the future, alpine storage lakes could increasingly serve to retain flood peaks. The use of multipurpose facilities will gain in importance.

Links to other topics

Agriculture

Agricultural demand for irrigation water, production losses due to shortage in irrigation water

Tourism

Effects of water-related natural hazards on tourism, effects of the changed water resources on tourism (lower water levels in lakes and streams in summer: bathing / passenger boating), water supply for snow-making machines

Energy

Production of hydroelectric power with reduced supply in summer/autumn, impact of extreme events on hydropower, impact of temperature increase on the use of cooling water by thermal and nuclear power plants with once-through cooling (Betznau and Mühleberg), changes in energy demand in summer and winter

Financial management

Investment needs, damage insurance

Infrastructure

Flood protection, irrigation plants, canalisation, linking-up of different systems in terms of integrated water management

2. Changes in natural waterbodies

Water temperature

Climate change directly affects water temperatures. In Switzerland, water temperatures in rivers and in the surface layer of midland lakes will have increased by about 2 °C by 2050 compared to 1990.[1] In midland lakes, the risk of oxygen deficiency in the deep water will increase.[2]

In the last decades, water temperatures in rivers have risen in parallel to air temperatures (fig. 1).[3] In lakes, the warming was stronger in the well-mixed surface layer than in the deep water. As a result, the stability of density layering has increased and the period of stable layering in summer lasts longer. In the lake of Zurich,[4] a mean warming of 0.24 °C per decade in the surface layer and 0.13 °C per decade in the deep water has been observed. Stable layering lasts about 2 to 3 weeks longer.

In the midland lakes with no regular ice cover, the frequency of mixing events in winter has tended to decrease. As a result of this, less oxygen reaches the deep water. This is not true of lakes at higher elevations that are regularly covered with ice; there instead, the mixing takes place earlier in spring and later in autumn.

According to the scenario, rivers will warm by about another 2 °C by 2050 compared to 1990. In the midland lakes, the surface layer will continue to warm more strongly than the deep water, and the stability and the duration of density layering will continue to increase. The length of the period during which complete mixing is possible will be further shortened, the frequency of complete mixing events will continue to decrease and oxygen input into the deep water will be reduced. In lakes where the oxygen content is sufficient today, the risk of oxygen deficiency in the deep water increases.

With climate change, the midland lakes at lower elevations are expected to freeze more rarely, and at higher elevations, the ice cover will last for a shorter period of time. In mountain lakes, the decrease in the annual ice cover will lead to an increase in biological production and an increased oxygen demand.

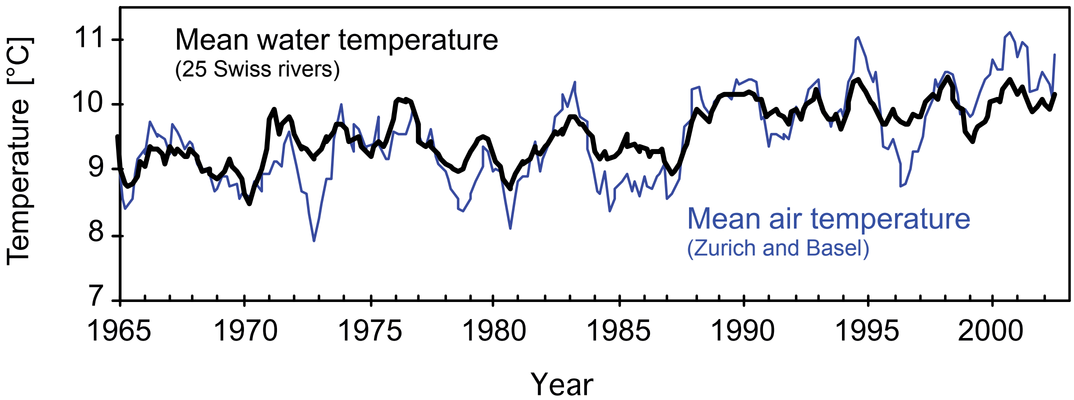

Figure 1: Since 1965, the increase in mean water temperature in Swiss rivers (black curve) has run in parallel to the increase in mean air temperature (blue curve).[3]

Micro- and small organisms

Water temperatures in the surface layer of lakes have increased in winter in the past decades, which has resulted in an increase in the thermal stability and a change in circulation conditions. This has resulted in temporal shifts in the food chain and, in lakes with sufficient oxygen content, in a decrease in phytoplankton diversity. As a consequence of future warming, living conditions in lakes with currently sufficient oxygen content may deteriorate.[2]

Today's state of knowledge does not allow comprehensive predictions to be made about the changes in aquatic biodiversity by 2050. Adaptability and adaptation speed are species-specific and cannot be predicted. However, single changes can be qualitatively foreseen.

In lakes, the food chain will undergo a temporal shift due to the warming. In spring, the feeding pressure of zooplankton ends algal bloom. What follows is the so-called "clear-water" phase. Since the growth and feeding rates of zooplankton are higher with warmer than with cooler water temperatures, the clear-water phase occurs earlier after warm than cold winters. In the past 20 years, the clear-water phase has been observed to occur about two weeks earlier. According to the climate scenario, the clear-water phase will continue to occur earlier in the future, although, this is not possible indefinitely.

Since the seventies, winter phosphate concentrations have decreased due to cost-intensive measures (wastewater treatment, closed circular pipeline). At the same time, an increase in phytoplankton diversity has been observed. In the past decades, warm winter temperatures have had a negative effect on phytoplankton diversity in lakes with sufficient oxygen content. This development will probably continue with future warming. In lakes without sufficient oxygen content, the influence is not clear.

Fish

The warming of waterbodies affects cold water fish; their suitable habitats are reduced and species composition changes. Cold and warm water fish will profit from the warmer winters.

For fish, human interference in the hydrology and morphology of waterbodies were important influencing factors in the past. This will also be the case in the future.

As a result of the warming in Swiss streams by 0.4–1.6 °C in the past 25 years (fig. 1), trout habitat has shifted upwards by 100–200 m.[3] A similar development was observed in North America: In the Rocky Mountains, the habitat suitability for trout decreased by 17% with a warming of the water by 1 °C in July.[5]

Estimates have shown that with a warming of 2 °C by 2050, the habitats of salmon in Switzerland will shrink by $^1/_5$ to $^1/_4$ compared to today. Cold water as well as warm water fish will profit from warmer winter temperatures; growth phases last longer and the fish grow more quickly. As a result, waterbodies will become more suitable for carp (Cyprinidae) and exotic fish species.

Illnesses like the parasite infection PKD (Proliferative Kidney Disease) will spread with warmer water temperatures.[6]

3. Water-related natural hazards

At elevations below about 1500 m a.s.l., more frequent and in part larger floods are expected in winter and spring as a result of climate change. In summer, drought periods will increase significantly.

Floods

The formation of floods is largely determined by the precipitation regime. In the past, there were periods with many floods as well as periods with few floods. In the past approx. 20 years, large floods seem to have occurred more frequently (summer 1987, September 1993, May 1999, October 2000, August 2005) in comparison to earlier decades in the 20th century.
An analysis of trends in measured runoff[7] of small and medium catchment areas in Switzerland (period 1930–2000) showed an increase in the annual discharge in many of the rivers studied. The increase was primarily caused by the increase in discharge in winter and spring. The observed increase in intense winter precipitation[8] can explain at least a part of the observed discharge trends.
According to today's knowledge, different changes in the precipitation regime that could affect flood frequency are possible in the future (see Background chapter). In winter, an increase in mean precipitation is expected. Precipitation will become more frequent and fall more often as rain instead of snow up into higher elevations. Both factors could bring about an increase in mean runoff in winter and into spring.[9,10] In addition, many analyses of global and regional climate models show that the mean precipitation intensity in winter and the frequency of heavy and extreme precipitation events could increase in Central and Northern Europe.[11,12,13,14] The analysis of recent model results also shows an increase in heavy precipitation in Central Europe for spring and autumn. Model results for summer display large variability. At present, qualitative statements for this season are almost impossible but in many models, the decrease in mean precipitation is accompanied by an increased precipitation intensity.[11,15]
In addition to the intensity and duration of precipitation events, the condition of the catchment area plays an important role in the formation of floods. Runoff ability will tend to deteriorate due to the increase in mean temperature and the decrease in precipitation in summer.
As a result of the expected changes in the precipitation regime, more frequent and in part larger floods are expected than under current climate conditions, in particular in winter and the transitional seasons, and mainly for medium and large catchment areas of the Jura, the midlands,

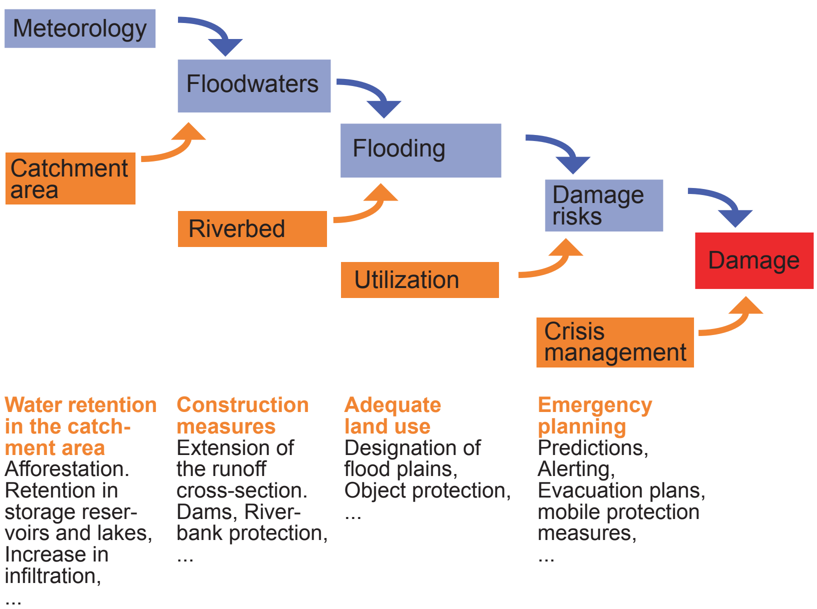

Figure 2:
Flood damage only occurs when a number of preconditions are fulfilled. The possibilities for intervention are accordingly numerous.

Redirection under overload conditions

In order to limit damage to a tolerable level in the case of an extremely large flood, the floodwaters are redirected to less vulnerable areas. In the flood of August 2005, this emergency measure was implemented. 25 to 50% of the flood discharge was directed onto sports fields, agricultural areas, car parks and other areas around the settlement area that were less sensitive to damage. Such measures must be prepared for with construction and spatial planning.

Figure 3: In August 2005, the flood of the Engelberger Aa was redirected around the vulnerable settlement area. (Source: Swiss Air Force 2005)

the foothills of the Alps and Ticino. In addition, the temperature increase will cause more frequent changes between snowfall and snowmelt, so that more often on the alpine border several days' accumulated precipitation results in runoff. Since evaporation is low in winter, no notable compensation effects are to be expected.

In small catchment areas of the midlands and in the Alps, the biggest floods usually occur in summer after short but heavy thunderstorms. It is very uncertain whether and in what direction a change in frequency will occur.

In the high mountains, floods are not expected to be affected significantly, since winter precipitation, even if it increases, does not generate floods due to the portion of snow. In spring, an intensification of snowmelt is expected. This could lead to an increase in flood risk when snowmelt and precipitation events overlap. Less meltwater and drier soils are generally expected in summer.

Flood damage results from the conflict between the natural extension of floods and human use of the catchment area (fig. 2). In the past 50 years, damage potential due to floods has markedly increased in the course of economic development. Infrastructure is increasingly located at exposed locations. The higher damage potential requires increased protection against floods irrespective of climate change.

Switzerland pursues a flexible strategy in flood protection, which, in the first instance, aims at avoiding damage rather than at preventing floods at all costs. It comprises a set of measures that given the uncertainties must be applied in combination. The following principles are thereby important:

- A further increase in damage potential is to be prevented by spatial planning measures; the construction of new buildings in areas at risk is to be avoided.

- For existing buildings and buildings in lower-risk areas, the damage potential is to be reduced by the appropriate property protection. In so doing, a further increase in the damage potential and the requirement for protective structures at watercourses can be reduced.

- Protective structure measures are taken if spatial planning and property protection do not suffice. Their design should be in accordance with economic principles, which implies a differentiation between protection goals, that is, higher values are to be better protected. Designs for existing settlements are usually based on floods occurring every 100 to 300 years.

- Independent of the validity of the calculated probability for design floods, an even larger flood can occur. Emergency planning must be arranged for such an overload case. This aims at limiting damage to a tolerable level in the event that the design flood is clearly exceeded. The concepts may include evacuations, mobile barriers or emergency discharge (see box).

The fundamental advantage of this strategy is the dimensioning of protective structures based on known probabilities. Their cost-effectiveness is therefore assured for today's conditions and even more so in a future climate with an increased risk of flood. The inclusion of a considerably larger flood in planning ensures damage limitation up to a certain degree, even in the case of an increase in flood risk. It saves time until a more reliable basis for the development of the risk situation is available. Continuous monitoring of the risk situation is a pre-condition for long-lasting effectiveness, since both damage potential and the danger conditions change continuously.

Drought

Switzerland experienced the last summer droughts in 1947 and 2003. For agriculture, the heat-wave summer of 2003 caused damage amounting to about 500 million Swiss Francs. However, there was not a life-threatening water shortage. In the course of the 20th century, no systematic trends in the frequency of rainless periods were detected.[8]

According to the scenario, precipitation will decrease in summer and the probability of drought periods will increase. Extreme drought periods will also become more frequent according to model calculations.

Today, Switzerland is in a favourable situation in comparison to other regions of the world. Plentiful precipitation as well as the balancing effect of snowmelt and – of decreasing relevance – glacier melt will provide comparably substantial water resources also in the future. In order to avoid shortages in water supply, the corresponding infrastructure needs to be appropriately upgraded in time. Requirement forecasts and construction periods need to be considered in the planning.

In discharge regimes in the high mountains, which are shaped by the winter snow cover and snowmelt, higher water levels might be reached during low water in winter, due to higher temperatures and increasing winter precipitation.

4. Water supply and demand

Groundwater recharge

Groundwater recharge will tend to increase in winter and decrease in summer and autumn as a result of climate change. Overall, groundwater levels will decrease slightly.

In Switzerland, 83% of the drinking and industrial water demand is covered by groundwater; 44% of which come from springs in karst and fissure aquifers and 39% from filter wells in unconsolidated rock (see fig. 4). Unconsolidated rock aquifers have a slow groundwater flow and are generally plentiful. In karst areas, the groundwater drains off quickly, which is why springs there show a large discharge after rain. Springs in fissured rock areas show a steadier discharge but are generally less plentiful. The different aquifer types therefore react to climate change to a different extent and with a different delay.

As a result of the predicted climate change, groundwater recharge will tend to increase in winter as a result of increased precipitation in the form of rain. In summer and autumn, groundwater recharge will decrease in the midlands and in the foothills of the Alps due to higher temperatures, more frequent drought periods and the concentration of intense precipitation. Infiltration from alpine surface waters will decrease slightly.

As a result of these changes in groundwater recharge, spring deliveries in near-surface wells with small catchment areas and in karst aquifers will fluctuate more strongly from season to season, and may partly run dry in summer and autumn. In groundwater reservoirs in valley gravels with a midland flow regime, groundwater levels are expected to fall in summer and autumn. Groundwater reservoirs in valley gravels with an alpine flow regime, which exhibit their seasonal peak in summer, will experience only slightly falling water levels. However, even here lower groundwater levels must be expected during the more frequently occurring heat wave summers and absence of glacier melt in late summer and autumn. In aquifers at lower elevations, a slight decrease in groundwater levels is also expected.

Figure 4: Distribution of the different aquifers in Switzerland.[16]

Demand for drinking and industrial water

As a result of climate change, competition between different water uses and users will become more frequent. The requirements for drinking water supply will be affected regionally and temporally. In agriculture, the demand for irrigation water will increase.

Climate change will affect the requirements for drinking water supply. The effects are regionally and temporally very different. Measures against drinking water shortages and to increase supply security include the use of surface water (lakes), the expansion of the integrated networks of the drinking water supply and the development of new groundwater resources.

Water resources will decrease in the soil due to decreasing precipitation in summer. Higher temperatures lead to an increase in evaporation and in the demand of plants for water (transpiration). As a result, longer-lasting and more frequent drought periods will lead to soil dehydration. Consequently, the water absorption capacity of the soil declines due to crustification and water retention capacity declines due to desiccation cracks; the ability to produce humus decreases.

Reduced water supply and increased agricultural demand for irrigation water will lead to a competitive situation between different uses und users, such as with downstream users. In summer, water – limited temporally and spatially – will increasingly become a scarce commodity. Thus, the necessity of suitable management will increase, which will affect the priorities, rights and prices for use. Compensation and irrigation measures will require rules as well as new infrastructure.

5. Water use

In Switzerland, water is extensively used for energy production. As a result of climate change, electricity production by storage and run-of-river power stations will decrease. In the future, Rhine shipping will increasingly be affected by extended periods with unusually low water levels.

Energy

In Switzerland, water power covers about 60% of the demand for electricity or $^1/_8$ of the entire energy demand.

Climate change will lead to a seasonal balancing of discharge regimes, particularly in the Alpine region. Water flow will increase in winter and spring, and decrease in summer and autumn. As a result, power plant operators gain more flexibility. In the future, the use of water-storage space will be adjusted not only to the balancing of seasonal fluctuations but also to the fluctuations of the electricity market. Overall, a loss in hydroelectric energy production by storage power stations must be anticipated, since less water will be available; annual rainfall will decrease and evaporation increase.

Low water levels in late summer and autumn will limit the electricity production of run-of-river power stations in the midlands. On the other hand, these power stations can profit from the increasing discharge in winter and spring, since the capacity of turbines at that time of year are hardly working to full capacity today.[17] Altogether, a minor decrease in electricity production by run-of-river power stations is to be expected.[18]

Floods and slope instabilities will increase with climate change, and in particular large mass movements can endanger auxiliary facilities of power plants, such as water catchments on steep slopes. Sediment, bed load and debris flow transport could increase, intensifying and accelerating the silting up of storage lakes.[19,20]

The production in nuclear and other thermal power plants will also be affected by climate change. Due to increasing water temperatures and decreasing discharge, they will not be able to obtain as much cooling capacity from the water as today, in particular during heat waves like in the summer of 2003.

Due to climate policy, water power as a renewable CO_2-free energy will gain economic advantages.

Rhine shipping

15% of the amount of foreign trade is transacted using Rhine ports; for mineral oil products this is as high as 35%. 9 million tons of goods are transported into Switzerland on the Rhine each year.

During low and high water, Rhine shipping may be restricted. In 2003, transported tonnage and transport performance showed a decrease of 5.8 and 9.9%, respectively. This decrease was primarily due to the low water levels in the second half of the year. Due to the low water, the ships were not able to carry as much compared to normal water levels. In the case of high water, Rhine shipping is suspended when a water level of more than 4.30 m at Rheinfelden is reached. In May 1994, the stretch between Basel and Rheinfelden was closed for 13 days. In February 1999, shipping was interrupted for five days and from 12 May until 16 June for another 38 days.

Climate change will have an impact on discharge. Today, the Rhine has a stabile discharge thanks to meltwater supply and precipitation in the Alps in spring/summer, and precipitation in lower lying areas in autumn/winter. The meltwater of the winter snow cover and of glaciers is currently an important source for regular discharge at times of low precipitation. This balancing effect will continually decline with the melting of glaciers. The probability of extended periods with unusually low water levels will increase by 2050. Although this will not affect the survival of Rhine shipping, it will probably affect the temporal reliability. Progress in the seasonal forecasting of weather dynamics and therefore of water levels will simplify logistic planning and enhance planning reliability.

6. Intensified management of water resources

Today, Switzerland has a spatially and temporally relatively stable water supply. Due to climate change, the natural water supply will not be able to cover the future demand everywhere all of the time.

As a result of climate change, alpine discharge regimes will become more stabile and the midland regimes will experience increasingly low water and dry periods. According to the climate scenario, heat waves and dry spells will become more frequent. This means that water – restricted temporally and spatially – will increasingly become a scarce resource in summer. The requirements for water utilisation will also change with climate change. In the case of low water levels, lake users and downstream neighbours will increasingly request an increase in discharge for shipping, water protection requirements, drinking and irrigation water extraction, and for recreation. The seasonally and regionally reduced water supply, and the change to the claims on water use make it necessary to manage water on a quantitative basis. Without water quantity management, it will not be possible to meet all demands to the same degree.

For regulated lakes, the existing regulating schemes need to be adapted to future requirements. For lakes that are not yet regulated (e.g. Lake Constance), the call for regulation will increase.

Intra-regional management means that water management facilities (integrated networks, as well as storage and lake management) would need to be accelerated in order to ensure the required balance between (natural) supply and demand.

Integrated management at the level of catchment areas requires administrative-institutional adaptations (revision of responsibilities, coordination) on the organisational level, as well as legal adjustments, since the small-scale responsibilities that have existed up until now do not provide an efficient structure.

Along with management approaches, measures are also required on the demand side, in particular for agriculture (from more efficient use of irrigation techniques to the choice of planted crops), and for industrial and drinking water.

Literature and notes

1 F. Peeters, D. M. Livingstone, G.-H. Goudsmit, R. Kipfer, and R. Forster. Modeling 50 years of historical temperature profiles in a large central European lake. In: Limnol. Oceanogr., 47(1), 2002, 186–197.

2 D. M. Livingstone and D. M. Imboden. The prediction of hypolimnetic oxygen profiles: a plea for a deductive approach. In: Can. J. Fish. Aquat. Sci., 53(4), 1996, 924–932.

3 R. E. Hari, D. M. Livingstone, R. Siber, P. Burkhardt-Holm and H. Güttinger. Consequences of climatic change for water temperature and brown trout populations in Alpine rivers and streams. In: Global Change Biol., 12, 2006, 10–26.

4 D. M. Livingstone. Impact of secular climate change on the thermal structure of a large temperate central European lake. In: Clim. Change 57, 2003, 205–225.

5 C. J. Keleher and F. J. Rahel. Thermal limits to salmoid distributions in the Rocky Mountain Region and potential habitat loss due to global warming: a geographic informations system (GIS) approach. In: Transaction of the American Fisheries Society 125, 1996, 1–13.

6 P. Burkhardt-Holm, W. Giger, H. Güttinger, U. Ochsenbein, A. Peter, K. Scheurer, H. Segner, E. Staub, and M J.-F. Suter. Where have all the fish gone? In: Env. Science & Technology 39 (21), 2005, 441A–447A.

7 M. V. Birsan, P. Molnar, M. Pfaundler und P. Burlando. Trends in schweizerischen Abflussmessreihen. In: Wasser Energie Luft, Heft 1/2, 2004, 29–38.

8 J. Schmidli and C. Frei. Trends of heavy precipitation and wet and dry spells in Switzerland during the 20th century. In: Int. J. Climatol., 25, 2005, 753–771.

9 F. Bultot, D. Gellens, B. Schädler and M. Spreafico. Effects of climate change on snow accumulation and melting in the Broye catchment (Switzerland). In: Clim. Change, 28, 1994, 339–363.

10 J. Kleinn. Climate change and runoff statistics in the Rhine basin: A process study with a coupled climate-runoff model. Diss. ETH Nr. 14663., 2002.

11 J. Räisänen, U. Hannson, A. Ullerstig, R. Döscher, L. P. Graham, C. Jones, H. E. M. Meier, P. Samuelsson, and U. Willén. European climate in the late twenty-first century: regional simulations with two global models and two forcing scenarios. In. Climate Dyn., 22, 2004, 13–31.

12 M. Ekström, H. J. Fowler, C. G. Kilsby, and P. D. Jones. New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 2. Future estimates and use in impact studies. In. J. Hydrol., 300, 2005, 234–251.

13 C. Frei, R. Schöll, S. Fukutome, J. Schmidli and P. L. Vidale. Future change of precipitation extremes in Europe: An intercomparison of scenarios from regional climate models. In: J. Geophys. Res. Atmospheres, 111, 2006, D06105, doi:10.1029/2005JD005965.

14 OcCC (Hg.). Extremereignisse und Klimaänderung. Bern, 2003.

15 J. H. Christensen and O. B. Christensen. Severe summertime flooding in Europe. Nature, 421, 2003, 805–806.

16 BUWAL. Wegleitung Grundwasserschutz. Vollzug Umwelt. Bundesamt für Umweltschutz, Wald und Landschaft, Bern, 2004.

17 D. Vischer und S. Bader. Einfluss der Klimaänderung auf die Wasserkraft. In: Wasser Energie Luft, Heft 7/8, 1999.

18 M. Piot. Auswirkungen der Klimaänderung auf die Wasserkraftproduktion in der Schweiz. In: Wasser Energie Luft, Heft 11/12, 2005.

19 IG Wasserkraft, VSE, ProClim, OcCC, NCCR Climate. Wasserkraft und Klimawandel in der Schweiz – Vision 2030, 2003.

20 A. Schleiss und C. Oehy. Verlandung von Stauseen und Nachhaltigkeit. In: Wasser, Energie, Luft, 94 (7/8), 2002, 227–234.