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Climate Change in Switzerland

Effects of Extreme Precipitation Events

Assessment Report

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Preface

Climate Change: Switzerland Must Act!

A temperature increase of over 1°C, and an increase in winter precipitation of between10 and 30%—these are the currently known facts regarding 20th century climate change in Switzerland. Considering the changeability of daily weather patterns, these figures appear to be fairly unspectacular, and the change has been occurring at an almost imperceptible rate. Nevertheless, researchers worldwide now maintain that global climate has been affected by a discernible human influence. At conferences in Kyoto or Buenos Aires, delegates from all over the world have discussed ways in which global climate change and the threat of its impacts might be mitigated.

Owing to its convenient location at the heart of Europe, Switzerland is only rarely affected by extreme weather events. Such destructive storms as 'Vivian' in 1990, or the floods of Uri in 1987 and Brig in 1993 should, however, remind us that the climate can wreak havoc here as well. OcCC, the Advisory Body for Climate Research of the Swiss Federal Government, has therefore commissioned a Position Paper using extreme precipitation events to show current and likely future impacts of climate change in Switzerland.

One likely consequence of global climate change is the intensification of the hydrological cycle. Climate models for Switzerland therefore predict a further increase in winter precipitation. Together with rising temperatures and a receding snow line, this is likely to lead to an increase in high water levels in winter. Although this does not directly point to a greater frequency of floods, the trend is clear: we must expect increasing flood damage.

Over the past 25 years, floods have cost Switzerland 450 million Swiss francs annually. While economists expect the likely increase in flood damage to have drastic implications, they also expect them to remain below the critical level. As long as future floods are no worse than those of the 20th century, damage will be limited and can be covered by conventional insurance. Only large-scale floods - such as they have occurred in the earlier past - could cause damage going into the billions and therefore impossible to be covered by insurance. Owing to the infrequency of such events, however, statistical methods cannot help us predict whether large-scale floods will occur more frequently; neither does our understanding of the processes involved permit us to make confident predictions.
Should we sound the all-clear, then, and go back to business as usual?

This is not an intelligent strategy. Both global insights and current research results show an alarming trend. While current atmospheric greenhouse gas concentrations are not very likely to lead to a climate catastrophe, the slow, almost imperceptible seasonal changes can have serious negative impacts on our economy, both directly and indirectly.

The recommendations by the experts involved in producing the OcCC report identify key areas where action is required. Also, while Switzerland should not pursue an isolated climate policy but needs to become active at an international level, a national 'climate strategy' is essential to ensure international success. Such a strategy should focus on the following elements:

1. National actions to promote sustainable, resource-conserving technologies and incentives for emission reductions;
2. Promotion of research to close gaps in our knowledge;
3. Actions to mitigate effects.

It is more intelligent to act with caution now because tomorrow - when we can be certain of what is happening - it may be too late!

Prof. Gian-Reto Plattner
President OcCC

Summary and overview

1 Climate change and natural disasters 7

Serious worldwide consequences associated with climate change are expected unless greenhouse gas emissions are significantly reduced. For Switzerland, the impact of natural disasters — especially flooding, which tends to cause particularly high levels of damage — is a key issue. In this Assessment Report, we discuss the frequency and potential economic impact of heavy precipitation events and droughts in Switzerland.

2 Climate, extreme precipitation and runoff 9

Over the last few years, research has provided an improved understanding of the processes leading to extreme precipitation and flooding. Thanks to modern climate models, accurate estimates of changes in the average climate in the average future climate are achievable. However, these models do not provide definitive statements concerning future extreme precipitation events. Nevertheless, weather forecasting models allow detection of the formation of such events days in advance.

At present, the processes that cause prolonged droughts in the Alpine region are poorly understood.

3 Frequency of precipitation/flood-related events 15

According to climate models, intensification of the hydrologic cycle due to anthropogenic climatic warming is likely. Indeed, recent studies based on the 100 year observational record in Switzerland confirm model-based predictions: There has been an increase of up to 30% in autumn and winter precipitation in the Alps, and we may well see a further rise in the future. As a result, the frequency of flood events in the Swiss Central Plateau (Mittelland) and southern Switzerland in the winter half-year is expected to increase.

Little change in the magnitude of summer precipitation has been observed, and its future pattern is uncertain. This makes it virtually impossible to predict the impact on the flow patterns of Alpine rivers, which flood primarily in response to summer storms.

4 Economic impact of extreme precipitation events 19

The economic impact can be assessed on the basis of three scenarios:

- A *seasonal drought* would not have serious economic consequences, as Switzerland has sufficient water reserves.
- If *regional flooding* were to increase, we should expect costs to rise by several hundred million francs per year. Broadly speaking, existing insurance schemes, reinsurance agreements and solidarity agreements should be able to absorb this additional risk.

- Historical climate records indicate that *extreme precipitation* events could occur on a far greater scale than they have in recent years. The resulting damage-related costs would far exceed current insured amounts. However, since such events are rare, this issue cannot be linked to climate change.

5 Measures for reducing future flood-related damage 24

Measures for preventing flood-related damage can be directed at different points in the precipitation/flooding/damage chain of events.

- Switzerland is well advanced in terms of *construction-related measures*. However, there is a clear need for overall evaluation when new investments are being planned.
- *Land-use planning* is likely to become more important as the risk of flooding grows, since effective planning reduces the potential for damage.
- *Unilateral reduction of greenhouse gas emissions in Switzerland* will not have any direct impact. Switzerland can best serve environmental policy needs by becoming involved at the *international* level in efforts to reduce greenhouse gases. This includes reducing emissions at the national level.

6 Synthesis and action to be taken 28

Various institutions should make efforts to respond to increases in the frequency of flood events:

- *Research institutions* should make further improvements in their climate, weather forecasting and natural disaster models. In addition, improvements are required in the basic principles of damage-related cost estimates and cost-benefit analyses relating to protection measures.
- *Insurance companies* should, among other things, reassess their coverage levels and develop premiums based on appropriate levels of risk.
- *Government* is challenged on all levels:
  - At the municipal level, land-use planning should take into account flood protection measures;
  - At the cantonal level, guidelines and funds for flood protection measures should be used more effectively;
  - At the national level, land-use planning must be coordinated more effectively. Funds for construction-related flood protection measures should be used more effectively. In addition, the government should undertake diplomatic initiatives with the aim of forging international environmental and climate agreements.

1 Climate change and natural hazards

Introduction

One of the consequences of the expected climate change could be an increase in natural hazards. The general public tends to interpret weather-related natural hazards as a sign of climate change. Of the natural disasters occurring in Switzerland, flooding has caused the most damage. There is therefore enormous concern about the damage levels to be expected in the future. In this report we discuss current research into the influence of climate change on extreme precipitation events and investigates the potential impact on the Swiss economy.

The international sphere

Globally, the risks associated with climate change relate to the following: damage to populated areas, areas of economic significance and ecosystems; rising sea levels; and a possible increase in natural disasters (IPCC 1996). Major economic and social consequences around the globe are expected if greenhouse gas emissions cannot be significantly reduced.

One of the key tasks facing international environmental policy-makers is to reduce anthropogenic influence on climate. As part of the United Nations Framework Convention on Climate Change (UNFCC), 159 nations have agreed to keep the concentration of greenhouse gases in the atmosphere at a level that will prevent dangerous anthropogenic disruption of the climate system (Article 2).

Under the terms of the Kyoto Agreement, initial steps have been taken towards limiting greenhouse gases in a coordinated manner at the international level. Switzerland has agreed to reduce greenhouse gas emissions by 8% relative to 1990 levels by 2010.

Current research concerning the impact on Switzerland

The National Research Program (NFP) 31 "Climate Change and Natural Disasters" and the Swiss Priority Programme Environment (SPPU) have succeeded in identifying problems and analyzing the impact of climate change in Switzerland (Bader and Kunz, 1998). These projects also focused on the link between climate change and extreme events and potential risks relating to natural systems. International research confirms the findings set forth in these studies.

For Switzerland, flood events are one of the greatest natural hazards (Federal Office for Civil Defence, 1995). NFP 31 studies indicate that an increase in flood-related damage would constitute a substantial proportion of all climate-change-related costs. Business leaders, politicians and the general public are all gravely concerned about the possible impact of climate change on natural hazards.

The OcCC is essentially an interface between research institutions, administrative bodies and the general public. This effort to assemble all current research on possible costs of extreme precipitation events in Switzerland will allow a determination of whether an urgent need for action exists.

This report, which is based on current international research into the impact of climate change on precipitation, assesses the possible impact on precipitation and runoff patterns in Switzerland. Damage-related costs resulting from potential flood events are also compared with corresponding historical costs.

The consequences of changes in mean levels of precipitation on other sectors of the Swiss economy, for example agriculture and tourism, are not discussed.

Photo: National Platform Natural Hazards, PLANAT

witzerland, flooding is amongst the ıral disasters causing the most da- ȷe. Example: Reuss in Seedorf (Uri), ust 27, 1987

2 Climate, extreme precipitation and runoff

2.1 The global impact of climate change

«The balance of evidence suggests a discernible human influence on global climate» (IPCC, 1996)

Concentrations of greenhouse gases in the atmosphere, particularly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), have risen significantly since the end of the pre-industrial era, around 1750 (IPCC, 1996). This has largely been due to human activities, in particular burning of fossil fuels and changes in land use and agriculture. The rise in greenhouse gas concentrations affects climate in the following ways:

- The bottom layer of the atmosphere absorbs more infrared radiation, leading to an increase in the temperature of the earth's surface.
- The global hydrologic cycle intensifies, amplifying the natural greenhouse effect associated with water vapour.
- Atmospheric and ocean currents are affected.

The atmospheric residence time of many greenhouse gases can be decades to centuries; they thus influence climate for long periods before they are decomposed deposited.

Aerosols also play a role. They are microscopic particles, largely produced as a result of combustion, which accumulate in the air. In contrast to greenhouse gases, the presence of aerosols in the stratosphere tends to cool the atmosphere. However, their primary effect tends to be for limited periods and over limited areas. Aerosol concentrations play their most significant role over heavily industrialized regions. As aerosols have a short atmospheric residence time, their levels are largely a function of fluctuations in emission rates.

Globally, the warming effect associated with increased greenhouse gas concentrations is more pronounced than the cooling effect associated with aerosols. Indeed, over the long term (several decades) the impact of greenhouse gases outweighs the impact of aerosols, even in heavily industrialized regions (IPCC, 1996).

Climate projections based on current global circulation models forecast the following changes (changes whose physical mechanisms have been identified) for the period up to 2100 (IPCC, 1996; ProClim-, 1996):

- An increase of between 1 and 3.5ºC in the average global air temperature at ground level. The most likely estimate is 2ºC.
- A 15-95 cm rise in sea level. The most likely estimate is 50 cm.

In addition:
- In winter, the air temperature above land will increase more dramatically than over the ocean.
- The air will warm up most dramatically in winter at high latitudes. It will warm up least dramatically in summer at low latitudes.
- The average global hydrological cycle will intensify.
- In winter, precipitation volumes at middle and high latitudes will increase.

2.2 Providing evidence of climate change

It is extremely difficult to provide evidence of anthropogenic climate change. First, dramatic variations in climate are a natural phenomenon. Second, instrumental record is at most a few hundred years long. Third, the climate system is highly complex. Nevertheless, considerable progress has been made over the last few years, particularly in global climate models and the use of historical and instrumental data.

Statistical methods can be used to *provide evidence* of climate change. It has been shown that the observed increase in the average global air temperature at ground level over the last 100 years is very unlikely to be purely of natural origin (IPCC, 1996).

Numerical models have been used to *determine the causes* of this human influence. When forced with increased greenhouse gas and aerosol concentrations and lower stratospheric ozone levels, these models are able to reproduce specific patterns in currently observed temperature changes in certain areas and over certain periods. It has therefore been concluded that there is a link between the increase in greenhouse gas concentrations and the increase in the average global air temperature at ground level (IPCC, 1996). In Switzerland, data analysis points to a temperature increase of just over 1ºC this century, which is more dramatic than the mean global increase (Beniston et al., 1994; Bader and Kunz, 1998).

However, it should be noted that it is very difficult to infer climate change from the frequency of extreme events, as such events are by definition rare. Moreover, the instrumental data currently available were not taken over sufficiently long periods, and are too heterogeneous, to definitively point to long-term changes (see Figure 1).

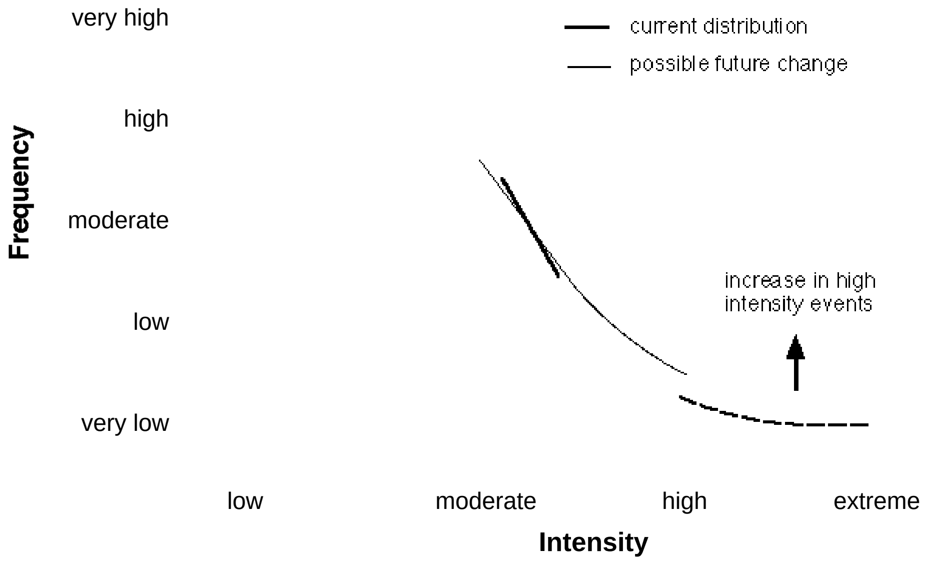

Fig. 1: Distribution curve for daily precipitation events. Intensity is based on a logarithmic scale. The broken line represents the part of the curve for which it is not possible to make statistically well founded statements regarding trends in frequency based on current data.

2.3 Extreme precipitation and flooding in the Alpine region

Over the last few years, research has provided an improved understanding of the processes that lead to extreme precipitation and flood events. As a result, we can now make statements about possible changes in the Alpine region.

Causal relationship sequences in the Alpine region

The physical mechanisms that influence Switzerland's climate can be plotted against a number of different scales (Wanner et al., 1997; Schär et al., 1998b; Grebner and Roesch, 1998. See also Figure 2).

Because insolation levels at the equator and the poles differ, a global temperature gradient is created, and a strong wave-like westerly flow is generated in the mid-latitudes of both hemispheres. The instability of this flow causes large-scale troughs of low pressure and ridges of high pressure to be formed. These not only affect weather conditions but also generate and influence smaller areas of high and low pressure. Large-scale troughs and ridges cause prolonged periods of precipitation/dryness lasting more than three days and corresponding responses in large river systems. On the *regional scale*, areas of high and low pressure influenced by troughs and ridges are responsible for variations in weather and daily precipitation. In the Alpine region, precipitation volume and intensity are also strongly influenced by topography. The Alps alter the development of and path taken by regional precipitation systems (low pressure systems and fronts) and influence local precipitation processes in a complex manner.

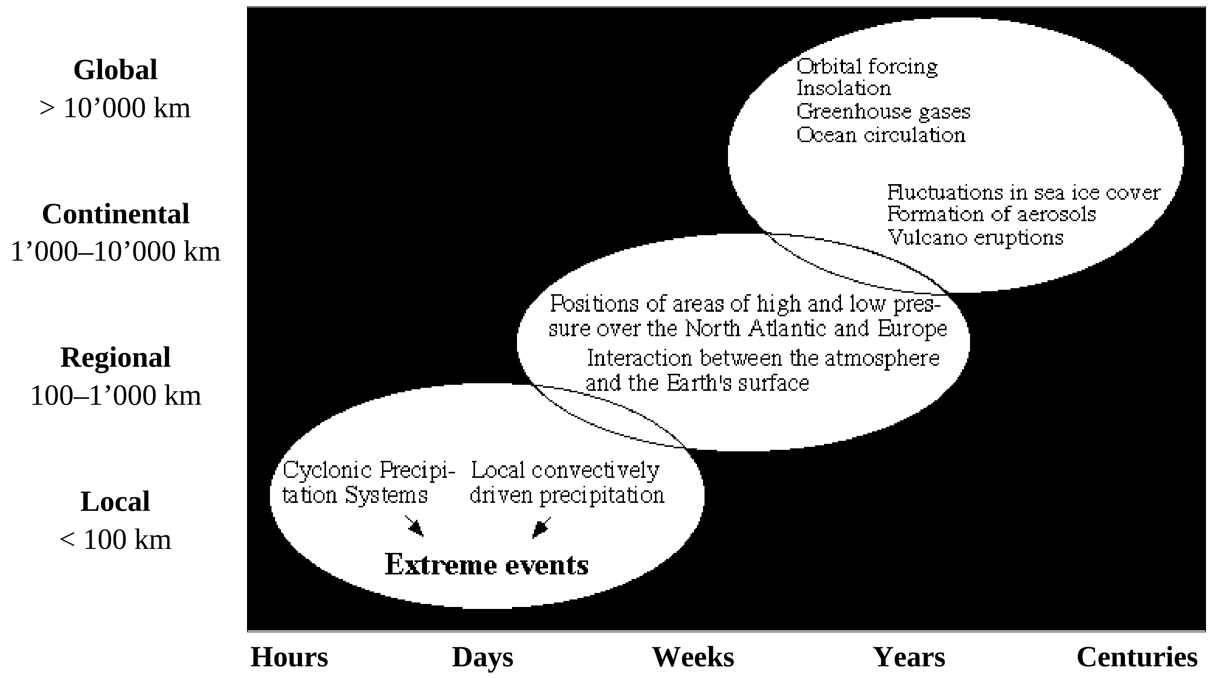

Fig. 2: Principle factors (plotted against time and physical dimension) affecting precipitation events in Switzerland. Most of these processes and their direct impact are well understood. However, there is enormous uncertainty regarding the interrelationship between the different scales, in particular the mutual interaction between climate and large- and small-scale weather phenomena.

The processes that cause extreme precipitation events

There are two principle processes that cause precipitation. They differ in terms of the duration of precipitation events and the size of the areas affected:

- *Convective processes* (showers and thunderstorms)
- *Cyclonic processes* (steady rain)

Convectively driven precipitation events are short in duration (several hours) and affect a limited area, but may be very intense. Convection mainly occurs in the summer. Damage resulting from runoff is local, and involves debris flows and flooding of mountain streams and small catchment areas (Kienholz et al., 1998; Zimmermann et al., 1997). Convectively driven precipitation is less intense in the central Alps than in pre-Alpine areas (Grebner and Roesch, 1998; Frei and Schär, 1998). There is an associated risk of damage due to high winds and hail (Schiesser et al., 1997).


Photo: PLANAT

k runoff of the Saltina in Brig,
tember 25, 1993

Precipitation caused by an area of low pressure can last up to three days. Intensity per hour is less than 20% that of convectively driven precipitation. Much precipitation associated with cyclonic systems occurs in the winter half-year, especially during autumn. Precipitation is caused by individual areas of low pressure and by prolonged series of low pressure systems lasting several days to several weeks. The longer a cyclonic flow situation lasts, the larger the area affected (individual river systems or entire regions and countries).

In the Alpine region, the highest precipitation intensity is observed south of the main ridge of the Alps. Particularly in the autumn, extreme precipitation is very frequent in Ticino and the neighbouring areas of northern Italy (Courvoisier, 1998; Frei and Schär, 1998). These events are often caused by a combination of precipitation associated with cyclonic systems and local convection. Moisture carried from the Mediterranean region by active areas of low pressure also plays an important role (Grebner, 1980; Buzzi and Tartaglione, 1995; Massacand et al., 1998).

Runoff mechanisms and flood development in Switzerland

The average flow for a body of water over the course of a year is known as the flow regime. This is mainly a factor of the catchment area's mean altitude and its position with respect to the Alps. For most rivers in Switzerland, the flow regime is at a maximum (maximum average flow) between spring and summer, due to melting snow. After the thaw period, and in the autumn, flow rates fall off again and approach the winter minimum (Grabs et al., 1997; Gurtz et al., 1997).

By contrast with the flow regime, individual runoff values and hence flood events are individual phenomena, and largely depend on the following factors:

- Precipitation volume associated with an event
- Type of precipitation (shower or steady rain; rain or snow).
- Condition of reservoirs (glaciers, snow cover, vegetation, ground)
- Evaporation
- Size of catchment area, and length of time and size of area affected by precipitation

Several additional components are important variables in flood formation:

- Type of ground cover (rocks, glacier, vegetation, residential area)
- Type of vegetation (meadow, forest, cultivated land)
- Ground characteristics (structure, degree of compression, soil type, saturation level)
- Construction measures (canals, drainage systems, overflow areas, sealed ground)

In addition, the position, size and characteristics of the catchment area in question are important variables governing a river's peak flow. It is therefore difficult to come up with general estimates for flood risk.

2.4 Extreme drought

The processes that could lead to prolonged drought in the Alpine regions are poorly understood.

Relatively little research has been done on the dynamics and climate-related factors associated with prolonged drought in central Europe and Switzerland. The processes which influence such events in the Alpine region are still poorly understood. Moreover, definitive statements cannot be made about the possible impact of global climate change, as current models have limited spatial resolution. The relative ignorance of the physical aspects of extreme drought events is surprising given the socio-economic and environmental impact of prolonged droughts. Several events of this type that occurred this century provide good examples of the impact of drought (Grütter et al., 1948; Schorer, 1992).

2.5 Extreme events in climate models

Climate models provide estimates of changes in the average future climate. Although model scenarios for extreme events should be viewed with caution, they are useful research tools as they allow us to demonstrate the possible impact of global climate change on extreme events.

Global coupled atmosphere/ocean models enable us to estimate changes in global and continental averages. However, they have limited spatial resolution, and there is some uncertainty regarding the interrelationship between different atmospheric scales. Thus it is not possible to make definitive statements regarding anticipated average or peak values for specific geographic locations in the Alps or Switzerland. Yet these are the scales on which political, economic and social issues must be tackled. Estimates can be attempted at the local level using the following two methods:

- Statistical downscaling (Gyalistras et al., 1994). A statistical model is set up based on observed data. Thus a relationship is established between the large-scale atmospheric conditions and small-scale measured precipitation. This model can be used to establish a scenario for precipitation in Switzerland, with future atmospheric conditions based on global climate models being taken as the starting point. This procedure has been used in NFP 31 and the SPPU (e.g. by Overney et al. 1997).
- Regional scale numerical modelling. In this approach, a regional physical climate model with resolution of several tens of kilometres is incorporated into a global climate model for the Alpine region. The regional model is provided with boundary conditions calculated by the global model. A detailed scenario is then calculated for the Alpine region. The first models of this kind for Switzerland have been set up over the last few years (Ohmura et al., 1996; Lüthi et al., 1996).

Both procedures have supplied locally (< 100 km) interpretable scenarios for mean future temperature and precipitation conditions. These can be used as input values for impact models (e.g. hydrologic catchment area models or forest models). Although these forecast techniques can not yet estimate probabilities of the occurrence or extent of extreme events, they improve our understanding of the processes that could lead to extreme events.

The improved knowledge of physical processes acquired over the last few years has led to the development of numerical models that can be used to make short-range forecasts of extreme precipitation events, thus enabling preventive action to be taken when necessary.

3 Frequency of precipitation and flood events

Analysis of Swiss climatological records reveals the following: Over the last 100 years, winter precipitation has increased by up to 30%, and intense autumn and winter precipitation has become more frequent. It is impossible to say whether the probability of extreme events has increased during this period since the 100 year record is short relative to the recurrence period of extreme events.

3.1 Precipitation over the last 100 years

Analysis of trends in precipitation volume using daily data has revealed the following: Over the last 100 years winter precipitation volume in Switzerland has increased by up to 30% (Swiss Meteorological Institute, 1996; Widmann and Schär, 1997), even though there has been no significant increase in the number of days with precipitation. This increase has mainly been due to a change in the distribution of precipitation intensity. Indeed a trend towards more intense precipitation events in the autumn and winter, especially on the northern side of the Alps, has been observed (Courvoisier, 1998). It is possible that this trend is due to intensification of the hydrologic cycle resulting from the observed temperature increase this century.

No significant changes in summer precipitation levels have been observed.

The observed changes are within the range of natural climatic variation. Thus they are not necessarily associated with anthropogenic climate change. Nevertheless, the nature of the trend is in line with our current understanding of climate change and with the climate model calculations.

3.2 Flooding and high-water events over the last 700 years

One study of flood events of the last 700 years reveals that the frequency of flood events has fluctuated. During this timespan there have been periods with large numbers of flood events, and periods in which virtually no flood-related devastation was recorded (Pfister, in press). This confirms that extreme events of this kind are sensitive to global changes. However, the reasons for these fluctuations are currently unknown. Current research (Wanner et al., 1998) is focusing on hypotheses based on connections between North Atlantic pressure conditions, Atlantic ocean currents and changes in levels of insolation (sun, volcanoes).

Studies of past flood events also clearly show the following: The flood and high-water events observed this century are within the realm of natural variation. This conclusion is confirmed by studies of sedimentary material in Swiss lakes, which conclude that the extent of extreme flood events has not increased over the last 1,000 years. To date, the largest-scale event found in these sedimentary materials is that of 1342 (Siegenthaler and Sturm, 1991).

Thus the current knowledge of flood event trends does not suggest any link to anthropogenic climate change. Nevertheless, an important result of these reviews of climate change is as follows: Extreme flood and high-water events have

tended to occur with greater frequency during transition periods between colder and warmer climates and vice versa (Pfister, in press).
Trend analyses of the instrument-based record reveals that there has been an increase in mean streamflow in Switzerland's major rivers (Schädler, 1987). Overney et al. (1997) have also observed non-stationary phenomena in six catchment areas. However, a systematic increase in damage-causing flood events has not been demonstrated, because the rarity of extreme events makes trends in occurrence difficult to establish.

3.3 Statements regarding precipitation events in the future

Atmosphere temperature increases tend to intensify the hydrologic cycle. According to model-based calculations, this effect is associated with more frequent intense precipitation in autumn, winter and spring. It is still uncertain whether warming has any impact on summer precipitation.

Physical principles and global climate models suggest the following: An increase in temperatures close to the earth's surface at mid-latitudes leads to an increase in atmospheric moisture content. Given a 2ºC increase in temperature, there will be a 15% increase in atmospheric moisture content. This mechanism may lead to considerable intensification of the hydrologic cycle (IPCC, 1996).

As mentioned in Section 2.3, the outlook for extreme precipitation events depends primarily on large-scale atmospheric influences and on mesoscale conditions of the atmosphere (temperature, moisture). However, at present no estimates can be made concerning the future behaviour of these parameters.

Winter half-year

According to regional climate simulations, intensification of the hydrologic cycle in autumn, winter and spring contributes to an increase in annual mean precipitation. It is also associated with an increase in the frequency of moderately intense precipitation (Frei et al., 1998). The more intense the precipitation events, the more pronounced the relative changes. Indeed a 2ºC increase in temperatures might be accompanied by changes of over 10% (see Figure 3). Increased intensity of winter precipitation would have serious consequences, particularly on the southern side of the Alps, where autumn precipitation already causes major high-water and flood-related damage. In addition to intensification of the hydrologic cycle, currently incalculable changes in the frequency of certain weather situations might also occur. A retreat in the snowline would additionally cause runoff peaks to increase.

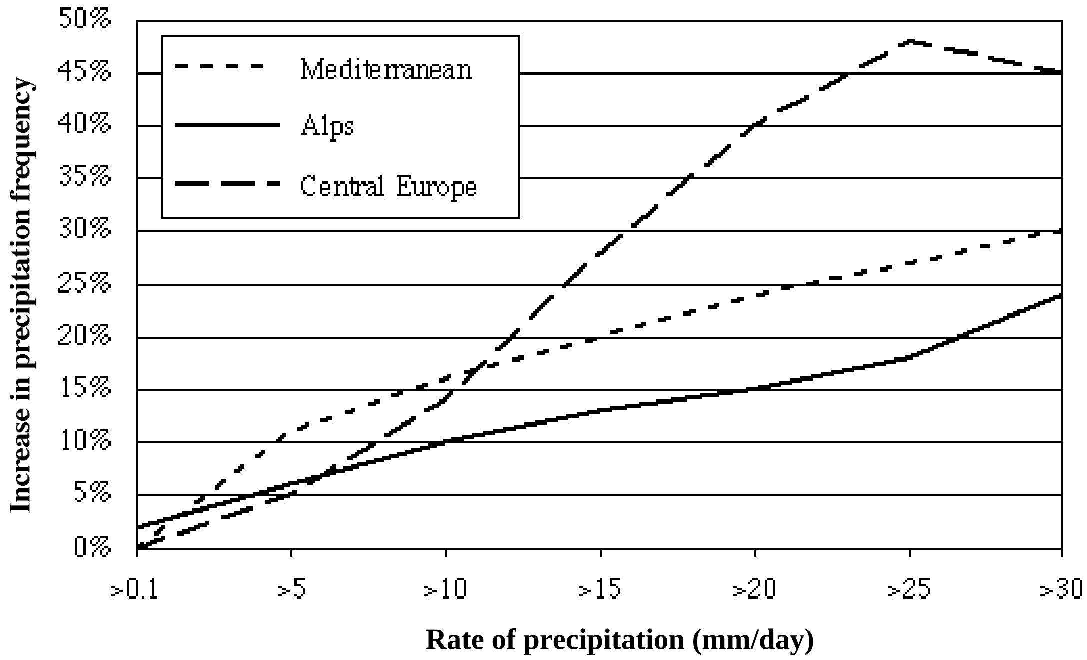

Fig. 3: Predicted increase in winter precipitation in three central European regions, given a 2°C increase in atmospheric temperatures and a 15% increase in atmospheric moisture (after Frei et al., 1998).

Summer half-year

The northern side of the Alps experiences most flooding (mainly due to convectively driven precipitation) in the summer half-year. At the moment, no conclusive statements can be made regarding future trends in precipitation. First, no significant trends have been observed. Second, the results from models for the summer half-year are inconclusive (Schär et al., 1998a). The improvement of the models over the next few years will particularly aim at incorporating the evaporative and convective processes that play a role in summer with greater precision in order to allow for more reliable results.

3.4 Statements regarding flood activity in the future

Anticipated changes in precipitation activity will cause a change in seasonal runoff behaviour. In the future, the mean frequency of winter flooding will probably rise, and that of summer flooding will probably fall somewhat. Risk to residential areas and infrastructure will be greater in the Alps than in the Central Plateau, due to the processes involved. At the moment, it is not possible to make any definitive statements regarding the probability of flood occurrence in the future or regarding future levels of flood- related damage.

Changes in the runoff regime in the Central Plateau

If the climate warms, there will be a change in runoff levels during the year: From December to March, average runoff is expected to increase. From April to September, it is expected to decrease. The increase in winter will be due to more precipitation falling as rain rather than snow. The decrease in summer will be due to increased evaporation, which might be accompanied by a trend towards decreased precipitation (Bader and Kunz, 1998; Grabs et al., 1997). Note that results regarding trends in summer precipitation levels are still very unreliable. The maximum early-summer runoff will decrease, and levels will be more balanced over the course of the year. In the Central Plateau, the summer could become the main low-water season, which means that cultivated land may have to be irrigated.

Changes in the runoff regime in the Swiss Alps

In Alpine catchment areas, the difference between mean summer and winter runoff will become less substantial. Mean winter runoff will increase, as retention by the snow cover is reduced. In summer, catchment areas influenced by glaciers will experience an increase in runoff as well due to increased meltwater runoff. As glaciers retreat, this effect will become less pronounced (Grabs et al., 1997; Gurtz et al., 1997).

Changes in flood risk

Based on knowledge acquired to date, predictions are limited to statements regarding average atmospheric conditions. Currently trends in variables which affect flood risk can be identified, but concrete data for individual regions or even the whole of Switzerland are not available.

In the Central Plateau and southern Switzerland, frequency of flooding in the winter half-year could increase somewhat. This is because various processes point to a trend of this kind for the winter half-year: The water content of the atmosphere will increase, more precipitation will fall as rain and less as snow, and the duration of extensive, water-storing snow cover will decrease (Gurtz et al., 1997; Schulla, 1997).

Currently no definitive statements can be made regarding future trends in small-scale summer floods in the Alpine region. This is because flood events of this kind are mainly caused by showers and storms, and no trends in their frequency can be identified, either in the past record or in model based future scenarios.

Photo: PLANAT

sion of the Varunasch,
chiavo, June 1988

Studies by Naef et al. (1998) have shown that the retention capacity of the ground in Switzerland would not be exhausted even if precipitation volume or intensity were to increase by 20%. Therefore, a disproportionate increase in surface runoff and flood risk is not expected.

4 The economic effects of extreme precipitation events

4.1. Chain of events and economic evaluation

The scientific chapters above attempt to describe the first section of the chain of events: changes in the atmosphere — changes in precipitation — flooding and drought — additional potential for damage — increased damage and to determine the probability of future high-water events. In the present chapter, the economic and social dimension of future flood hazards is presented.

The main economic concerns are damage due to flooding and drought, the economic impact of flood damage, human behaviour in response to such damage, and the evaluation of measures to reduce or prevent damage.

The scientific analysis does not clearly prove that the chain of events unavoidably leads from climate change to more frequent flooding, as the uncertainties inherent in an analysis of this type remain quite substantial. Thus, the economic analysis cannot directly incorporate the scientific findings. In economics, conclusions and evaluations are often fraught with uncertainty. It is important, however, not to conceal this uncertainty. Therefore, this economic evaluation of climatically induced flooding utilizes scenarios. Such *scenarios* allow conclusions to be reached regarding the likely consequences *if* increased flooding occurs.

Photo: PLANAT

Flood-related damage in
after the September 1
flood of the Sa

4.2. Precipitation scenarios

When discussing the effects of extreme events from a scientific or economic point of view, it makes sense to define scenarios based on historical experience. One proposal for evaluating the impact of extreme events is found in the impact classes used to categorize the effects of natural hazards in the KATANOS study (Federal Office for Civil Defence, 1995). Three scenarios were studied in this report.

- *Regional high-water event*: high-water event with severe local/regional impact (e.g. Uri, 1987; Brig, 1993; Sachseln, 1997).
- *Extreme high-water event*: flooding over large surface areas (entire regions of Switzerland), comparable to the floods which occurred in 1342. Events of this type occurred in Germany in 1993 and 1995.
- *Periods of extreme drought*. A year-long drought in central Europe, comparable to that experienced in 1540.

These three scenarios may be used as a basis for evaluating the economic consequences of extreme climatic events.

4.3. Regional high-water events

The frequency of regional high water events may increase due to increased wintertime precipitation. It is estimated that damage will be on the order of hundreds of millions of francs. Most of this damage can be absorbed by current insurance systems.

Additional damage potential of regional flooding

Regional high-water events occur repeatedly in Switzerland, both in the Central Plateau and in the Alps. The damage from such floods increased from 1815–85 but subsequently declined up to the mid-20th century. However, it has been increasing again since mid-century (Röthlisberger, 1998, Weingartner et al., 1998; Pfister, 1998). The reasons for these variations are not clear. It is uncertain whether the decrease in damage up to the middle of the 20th century was primarily due to climatic factors or whether it was due to planning and construction measures. Similarly, in attempting to determine the cause of the increase since the middle of the 20th century, it is not possible to establish distinctions between climatic factors and the increasing tendency to build in high-risk zones.

In NFP 31, the annual costs of weather-related damage were estimated to be CHF 450 million (based on 1995 prices, see also Meier, 1998). This figure was primarily derived from the WSL's inclement weather statistics over the period 1972—96 (Röthlisberger 1998), which are summarized in Figure 4. In the analysis below, we shall use these values to estimate the cost of damages caused by climatically induced flooding.

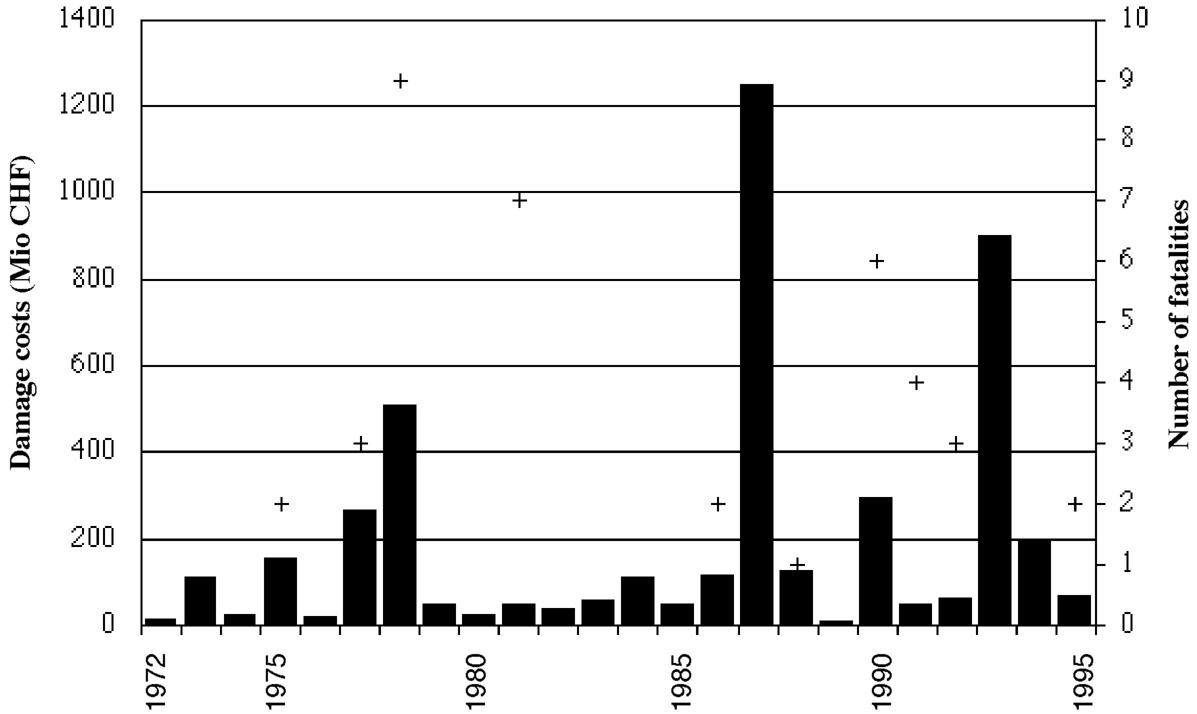

Fig. 4: Annual damage (bars) and fatalities (+) caused by high-water events in Switzerland (Röthlisberger, 1998; not corrected for inflation)

The "regional high water event" scenario assumes that increased and relatively heavy precipitation will cause additional damage exceeding current levels by 30–100%. This rough estimate cannot be verified statistically, but it is based on a series of plausible assumptions (Meier 1998). The chain of events leading to the damage may be affected by various factors in addition to heavy precipitation, such as an upward shift of permafrost lines, the increased frequency of debris flows and a weakening of the protective function performed by woodlands. Thus, an entire chain of events would presumably contribute to the potential damage. Under this scenario, additional flooding would cause damage amounting to CHF 135–450 million per year. These figures include the costs of evacuations, interruptions of business operations, and cleanup work.

Insurance coverage

Damage caused by regional flooding is largely covered by "acts of God" clauses in insurance policies. Cantonal building insurance policies have no limits on liability. Under federal legislation, private insurers are liable for up to CHF 300 million. In order to ensure that they can meet these obligations, private insurance companies have set up a common funding pool to cover damages resulting from natural disasters. In the event of severe damage (up to CHF 100 million per occurrence), cantonal insurers can rely on an intercantonal reinsurance scheme; in the event of very severe damage (up to CHF 750 million per year), the IRG (Intercantonal Risk Cooperative) can provide reinsurance assistance. Private insurers providing cover against damage due to "acts of God" also have their own pools. Damage to the public infrastructure is not insured and therefore must be borne by the federal government, cantons and municipalities.

Insurance limits may be reached in the event of regional flooding comparable to the 1817 flood in the Rhein river basin. Current estimates are based on a potential damage of over 1 billion (10^9) francs (Hausmann 1998). The St. Gallen Cantonal building insurance could just cover such damages (after taking account of the IRG-contribution this would amount to more than CHF 250 millions).

4.4. Extreme high-water events

Extreme high-water events could cause damage in the range of billions of francs. Damage of this magnitude cannot be covered by insurance policies — either now or in future.

Damage potential from an extreme high-water event

In the late Middle Ages (1342) exceptionally high water levels caused extreme and extensive flooding in western central Europe (Pfister, 1998). This "once in a millennium" flood was characterized by water levels which exceeded any peaks recorded since then. This event allows us to examine the consequences of a flood catastrophe affecting large areas. Owing to its unique nature, however, this event cannot be linked to specific causes. Therefore, the following sections only discuss what would happen if such a high-water condition were to occur in the future.

Catastrophic flooding on the scale experienced in 1342 would inundate valley infrastructures. The effects of this damage can only be assessed in general terms. It is assumed that order 5% of the national infrastructure would be affected. The extent of the damage would range from 7 to 20% (10% on average). This figure is based on extrapolation of empirical data from regional floods. Assuming a replacement value for Switzerland's entire civil-engineering and structural-engineering infrastructure of approximately CHF 2.4 trillion (1998), the total infrastructure damage would be approximately CHF 12 billion. In addition to this figure, losses of movable goods ("building contents") as well as consequential costs in the form of evacuations, human losses and production shutdowns would occur.

Limits of insurability

The damage that would result from an extreme high-water event would greatly exceed current insurance fund assets. If flooding of this type were to occur tomorrow, then, the bulk of the damage would have to be paid by the parties suffering the damage and by the government. Banks would also be affected by reductions in the value of mortgaged properties. It is unclear whether increased insurance protection is feasible for an extreme event of this type.

Extreme high-water conditions are, by definition, extremely rare occurrences. In other words, the probability of their occurring is extremely low, which means that the risk is low. However, potential damages are extremely high. The question is how to prepare for such events.

- Insurance against this type of damage is seldom taken out voluntarily. The reason for individuals not to sign insurance policies does not root in the lack of scientific data concerning the probability of an event (Borch, 1988) but rather in the individual's perception of the probability of an event. Moreover, people tend to underestimate the probability of extremely infrequent occurrences (Yates, 1992). Therefore, they are not prepared to pay the necessary premiums, even if, in principle, they are averse to risk [1] (Zweifel and Nocera, 1996).
- Mandatory insurance policies only provide a partial solution to the problem of inadequate coverage. If liability limits are increased through legislation, in some cases to the point where losses are covered completely, then premiums would increase massively for a longer period. The reason for this is not so much the inherent magnitude of the losses, but rather the impossibility of determining whether the event will occur in 10, 100 or 1000 years. In order to account for the possibility of an occurrence in the near future, insurance companies would demand very high premiums in order to accumulate cash reserves, Thiss would place an excessive burden on potential victims
- Earthquakes are natural disasters which are similar to extreme floods in terms of their insurance consequences. They seldom occur, but may result in heavy losses (far greater than a flood — see Bachmann et al., 1998). The San Fran-

[1] Risk aversion signifies that individuals faced with the choice between two event featuring the same product of damage and probability of occurrence will choose that with the lesser potential damage and the greater probability of occurrence (and, in extreme cases, that with a probability of 1). Risk aversion is thus a willingness to pay for avoidance of risk. In actuarial terms, it corresponds to the surcharge payable on top of the «neutral» insurance premium resulting from the product of probability of occurrence and the discounted potential damage («risk surcharge»).

cisco earthquake of 1906 caused damage running to trillions of Swiss francs (corrected for inflation). Most insurance companies were unable to pay the majority of claims. Because of the resulting bankruptcies, the losses had to be borne by the victims themselves (NZZ, 1998).
- An analogy can be drawn to nuclear energy. However, since nuclear power accidents are not a natural disaster, the parties causing the event are identifiable and, in theory, can be sued in civil proceedings. Serious nuclear energy accidents rarely occur, could cause losses in the trillions (Prognos/Infras/econcept, 1997). A loss of this nature, which exceeds the economic value-added of the facility, cannot be insured. For this reason, the liability limit for nuclear power plant accidents has been set at CHF 1 billion. Parties harmed by the accident must bear the remaining costs on their own.

Increasing liability limits or establishing public indemnity funds provide partial security. However, policy-makers and society as a whole should be aware that extreme but low-probability events are in general not coverable by insurance. An extreme high-water disaster would have to be paid for by the parties suffering the losses and, through economic feedback processes, by the economy as a whole.

4.5. Extreme drought

In Switzerland, the losses that would result from a one-year drought are relatively low.

Relatively long periods of drought occurred in 1947,1949 and 1976. These dry years are well documented (Schorer, 1992). The most extreme summer drought on record in Switzerland occurred in 1540. For ten months, virtually no precipitation fell on the north side of the Alps (Pfister, 1998). Over the past 500 years, Switzerland has not experienced any multiple-year droughts. Therefore, the following scenario is based on a single precipitation-free summer similar to that which occurred in 1540.

An extremely dry year will have adverse impacts on agriculture, hydro and nuclear power generation and water reserves for industry and household use. However, experience from 1976 shows that the consequences are not particularly severe. At that time, agriculture experienced losses totalling about CHF 100 million, and industry was largely able to cope using flexible water and power management techniques. Households were required to cut back on consumption in response to restrictions on water use.

The economic impact of periods of extreme drought in Switzerland would not be overly severe. At present, Switzerland has sufficient reserves of water in its Alpine glaciers. Severe consequences can therefore be avoided for the most part by modifying the water supply system and making changes in power consumption and production strategies. However, this situation could change if the Alpine glaciers were to recede drastically.

5 Measures to avoid future high-water damage

Damage results from high-water events due to the chain of cause and effect discussed above: atmospheric changes — changes in precipitation — high-water and drought — potential damage — damage. To avoid damage, intervention at any stage in this chain of events is, in principle, possible. It is possible to reduce the anthropogenic effect on the climate (e.g. by cutting back greenhouse gas emissions), reduce the occurrence of high-water incidents (through reforestation or structural measures in the catchment area), reduce the potential for damage (by appropriate land-use planning), and, finally, it is possible to minimize the damage itself (with structural measures or disaster relief).

Each intervention has its own cost-benefit ratio. To arrive at a policy decision to utilizing certain measures or a mix of measures, these cost-benefit rations would have to be quantified and compared. However, only qualitative evaluation is currently possible.

The following measures will be evaluated in this section:

- structural measures
- land-use planning measures
- measures to avoid anthropogenic greenhouse gas emissions

The "reforestation" option will not be pursued here since it would only be of minor impact due to the already high percentage of forested areas.

5.1. Structural measures

To date, structural measures to prevent high-water damage have been implemented based on once-in-a-century flood levels. Putting emphasis on enhanced structural measures can entail new risks. What is necessary is an improved overall evaluation of new investments.

In recent decades, Switzerland has made major investments in flood protection. The value of the entire flood protection system is between 4 and 5 billion francs. These investments have probably contributed to the reduction in flooding and high-water damage observed since the World War II. The annual cost of maintaining this system is approximately 40 to 50 million francs.

Existing protective structures have mainly been designed for high water levels with a probable return period of 100 years. However, this 100-year rule is arbitrary and does not take account of the varying potential for damage which can occur (e.g. differences between the impact on agricultural land and that on built-up areas). Further, investments in flood protection are often made where a flood caused damage rather than where the investments would have the greatest benefit over a relatively long period based on a comprehensive evaluation. The Federal Act on Hydraulic Structures, as amended in 1993, accordingly provides for a more sophisticated system of providing flood protection that not rely on the 100-year rule.

Stressing architectural protection can trigger a "calculated risk" effect familiar to the insurance industry: Because of the protection offered, people act in a more careless manner, thus again annihilating the protective effect. Such calculated risks are mainly encountered in land-use planning. If certain previously threatened zones are protected by architectural measures, then pressure increases on those responsible for land-use planning to allow use of the previously endangered zones. This behavior can result in greater flood damage over the long term (Swiss Re 1994).

In certain cases, allowing rivers to meander naturally can be an effective and often more cost-effective alternative to "hard" structural solutions to flood protection by providing extra room for the overflows and reducing flow rates (Swiss Agency for the Environment, Forests and Landscape, 1997). The additional land required can be provided in part by ecological compensation zones.

Photo: PLANAT

Structural measure to pre
flood-related dam
Durnagelbach, Gl

5.2. Land-use planning

> As the high-water hazards increase, land-use planning becomes much more important. Effective planning reduces the potential for damage. A concerted effort to strengthen the federal government's powers to control land use planning would be desirable.

The purpose of land-use planning is to utilize the land as efficiently as possible and to encourage appropriate settlement patterns. The most important tool employed by land-use planning is zoning. Floods affect the potential uses to which land can be put, and threaten existing use in particular. If the climatically related risk of flooding increases in Switzerland, land-use planning measures will become substantially more important (Bloetzer et al., 1998).

In recent years, land-use planning authorities have dealt intensively with the issue of natural disasters (Bloetzer et al., 1998). With regard to preventing flood damage, land-use planning requires both, "data analysis" and "actions":

- *Data collection*: hazard maps, risk analyses and basic process oriented research can reveal where, how frequently, how extensive, and at what intensity high-water and floods are to be expected. Such analyses of data form the basis for land-use planning.
- *Measures*: In terms of land-use planning, an arsenal of measures exists for reducing flood damage: If the surface-area requirements of rivers and streams are adequately taken into account, and if the hazard zones are withdrawn from intensive use, the potential for damage will be reduced. Monitoring construction activities that cap the soil, or even removing such sealing structures, will reduce runoff and thus the danger of flooding. These and other measures are part of effective land-use planning.

Currently, decisions affecting land-use are largely made at the municipal level. The federal government — and, to some extent also the cantons — has only a limited ability to influence municipal land-use planning. Since each municipality primarily plans for its own needs, the external impact, such as the effects on other municipalities or cantons, is rarely taken into account. A classic example is the exclusion of overflow zones to benefit downstream areas. Moreover, the tendency to yield to pressure to develop land is strongest at the municipal level.

The federal government and cantons can indirectly influence land-use planning decisions. For example, the federal government has the option of only authorizing investment grants if proper land-use planning has been carried out. Examples of such legislation include the Forestry Act and the law on hydraulic structures as amended in 1993. Moreover, the separation of developed and undeveloped areas provided for in the Land-Use Planning Act gives the federal government and the cantons the option to prevent new uses of threatened zones. Another important issue which will arise if flooding risk increases is the extent to which higher levels of government will need to play a more central role in coordinating decisions affecting land use.

In addition, insurance companies can support land-use planning by demanding premiums that reflect actual risks. If insurance premiums are made to more accurately reflect the degree of risk for a given site, construction in high-risk zones can be made unattractive.

5.3. Reducing greenhouse gas emissions

International stabilization and reduction of greenhouse gas emissions can reduce the danger of climatically induced events. Switzerland should continue its own efforts to achieve such reductions and should actively support the signing and implementation of international treaties on the environment and the climate.

Action to tackle the cause of a possible increase in high-water events and flooding will involve the stabilization and reduction of greenhouse gas emissions. A large number of measures — both topical and potential — can be taken. These might include disseminating information, issuing regulations, entering into agreements, levying taxes etc. Various studies reveal that environmental taxes are an efficient way to reduce the output of greenhouse gases (e.g. Nordic Councils of Ministers, 1994). Yet to be determined are the secondary and tertiary effects of taxes, above all the effects on employment, growth and the taxation system. Under certain model assumptions, taxes levied in a framework of ecological tax reform can have positive effects on government finance, employment and growth. Unilateral Swiss action is considered to be controversial (see Staehelin-Witt and Blöchliger, 1997 for current discussions on the reduction of CO_2, environmental taxes and ecological tax reform).

National measures to reduce greenhouse gas emissions have the character of a public good: The costs of such measures are incurred in Switzerland, while the benefits accrue throughout the world. A reduction in Swiss greenhouse gas emissions does not have any direct effect on the climate, precipitation and flooding in Switzerland. These climatic effects will mainly be determined by international efforts to reduce the total global generation of greenhouse gases. Reducing the emissions of greenhouse gases for the sole purpose of reducing the threat of flooding in Switzerland would have a negative cost-benefit ratio.

However, in global terms, the reduction of greenhouse gas emissions represents an efficient way to stabilize the climate. Switzerland has repeatedly agreed to reduce greenhouse gas emissions, as in the Kyoto climate protocol of 1992. Therefore, a most efficient way in which Switzerland can work to reduce climate-induced damage effectively is to strive for international agreements to reduce these emissions. An internationally binding climate or environment treaty will deliver the greatest benefits for Switzerland in terms of environmental policy.

6 Synthesis and need for action

6.1 Changes in the hydrologic cycle

Research suggests that humans affect the earth's climate system. In particular, the increase in greenhouse gas concentrations in the atmosphere can trigger climate changes that affect the amount and intensity of precipitation and increase the risk of extreme high water and flooding. There is still a great deal of uncertainty as to the precise sequence of cause and effect and the actual changes which can be expected.
The key findings are summarized below.

Precipitation

Observations over the past 100 years show that, in addition to warming, a significant change has occurred in the hydrologic cycle: In the Alps, an overall increase in wintertime precipitation has been observed along with a rise in heavy precipitation events in autumn and winter. These observations are consistent with results from climate models, which suggest that the precipitation cycle will intensify as a consequence of anthropogenic global warming. Observed changes on precipitation during the summer are less pronounced than these wintertime phenomenon and their future patterns are uncertain.

Runoff regimes and high water

A warmer climate will affect river runoff regimes due to changes in the retention capacity of snow and ground surfaces. The average runoff regime will be more uniform over the course of the year; the early-summer peak will diminish and the low winter levels will be increased. This effect will be more pronounced in rivers in the Central Plateau than in those in the Alps.

In the Central Plateau and in southern Switzerland, changes in the atmospheric water balance suggest that the frequency of high water will increase somewhat in the winter half-year (in the autumn in southern Switzerland).

As for Alpine rivers, in which high water levels are mainly caused by thunderstorms, it is not yet possible to predict the frequency and extent of future high-water events given the uncertainty that exists regarding summertime precipitation.

6.2. Economic effects of extreme precipitation events

The economic effects of extreme precipitation events may be depicted using three scenarios:

- *High-water events with serious local or regional impact*, such as those which occurred in recent years in Uri, Brig or Sachseln. Such events may occur more frequently in future, causing additional damage amounting to several hundred million francs per year. This potential damage can be absorbed for the most part by existing insurance policies, reinsurance and solidarity agreements.
- *Extreme high-water events causing widespread flooding over large areas of Switzerland*. Such an event occurred just once (1342) in the last thousand years. If it were to occur today, it would result in damage on the order of billions of francs. Insurers' resources would be pushed to breaking point, and the damage would have to be paid for by the victims themselves and (via multipliers) by the economy as a whole. Given the rarity of such events, a relation to climate change cannot be established.
- *Periods of extreme drought* in central Europe extending over an entire year. A drought of this type would not have serious economic consequences in Switzerland as long as adequate water reserves are on hand (in the form of glaciers).

6.3 Guidelines for responding to future high-water levels

With a possible future increase in high-water levels, various institutions are challenged to take measures.

Research

There are still gaps in our knowledge of the physical processes and of the possible economic consequences of extreme precipitation events. To close these gaps, research will have to receive substantial financial support.

In the *scientific domain*, various fundamental atmospheric processes, including those leading to natural disasters, are not adequately understood. Knowledge of these processes must be broadened through a concerted international research effort. Of particular importance are:

- improvements of climate models, with a focus on process studies;
- intensification of monitoring activities for early detection of climate trends or changes in natural hazards; maintaining and enhancing monitoring networks in regions sensitive to climate change;
- increased evaluation of measured and modelled data and proxy data in order to broaden understanding of climatic variability;
- improvement of models used to predict weather and natural hazards in order to improve damage prevention efforts.

In the *economic arena*, the relationships between scientific and social systems are poorly understood. In particular, research should concentrate on issues relating to the detection, evaluation and management of risks:

- laying the groundwork for damage cost estimates; assessing public aversion to risk; and willingness to spend the necessary funds to prevent flood damage;
- making cost/benefit comparisons of various potential measures to avoid high-water damage.

Insurance companies

Insurance companies are recommended to emphasize the risk of increased climate-induced high-water damage, for example by calculating the funding required to cover risks or by developing premium schedules that reflect actual risks.

Policy

The key strategies and measures that are recommended to be implemented by the various levels of government to reduce high-water-related damage are:

- Adequate maintenance and optimization of existing *structural protective measures*, and emphasis on economic benefit analyses of new investments;
- *implementation of land-use planning measures*, above all modification of land-use planning to take high-water hazards into account and exclusion of certain areas from development in order to ensure that watercourses have adequate space to perform their drainage function;
- fulfilment of international *pledges to reduce greenhouse gas emissions*, and intensification of political and economic initiatives at the international level in order to arrive at binding environmental and climate treaties.

All three levels of government will be affected by these recommendations:

- *Municipalities*, by integrating protection against high-water phenomena into the land-use planning process;
- *Cantons*, by issuing planning guidelines and by ensuring efficient use of funds for protection against high-water phenomena
- The *federal government* through
  - greater coordination of land-use planning;
  - efficient utilization of the contributions to structural measures for containing high-water;
  - flexible responses to disaster relief requirements;
  - diplomatic initiatives to achieve international environmental and climate treaties.

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