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Forecast methods of hydrological hazard events for upland (Alpine) urban areas

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FORECAST METHODS OF HYDROLOGICAL HAZARD EVENTS FOR UPLAND (ALPINE) URBAN AREAS

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In the presented scientific work qualitative characteristics of typical modern prognostic models of dangerous hydrological phenomena based on the most common scenarios of climate change are analyzed. As the research areas, quite different in physiographical characteristics mountainous highly urbanized areas in the Alpine region of Europe and the slopes of the Great Dividing Ridge in Australia were chosen. The possible changes caused by the forthcoming climate change according to the most common IPSS scenarios were analyzed. As a result of the analysis of the simulated and measured hydrometeorological data, significant inaccuracies were noted and a conclusion was made about the expediency of using the models studied only for individual catchment areas. Based on model predictions, a certain increase in the risk of flooding in all studied areas was identified. Also, a comparative analysis of model hydrological data and socio-economic damage from floods showed the possibility of applying modeling, to assess the potential cost of future damage. In the end of the paper, the main conclusions and some recommendations on improving forecast models and reducing the damage from potential floods are given.

МЕТОДЫ ПРОГНОЗИРОВАНИЯ ОПАСНЫХ ГИДРОЛОГИЧЕСКИХ ЯВЛЕНИЙ В УРБАНИЗИРОВАННЫХ ГОРНЫХ (АЛЬПИЙСКИХ) СТРАНАХ

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В представленной научной работе анализируются качественные характеристики современных прогностических моделей опасных гидрологических явлений, основанных на наиболее распространенных сценариях изменения климата. В качестве ключевых точек исследования были выбраны достаточно разные по физико-географическим характеристикам горные урбанизированные территории в Альпийском регионе Европы и склоны Большого Водораздельного хребта в Австралии. В результате анализа модельных и фактических гидрометеорологических данных были отмечены значительные несовпадения в значениях максимальных паводков, что весьма важно для прогноза наводнений в данных территориях. Сделан вывод о целесообразности применения изученных моделей только для отдельных водосборных бассейнов. На основании модельных прогнозов (модель «HYPE», климатические сценарии RCP 4.5 и RCP 8.5 IPCC) было выявлено однозначное увеличение рисков возникновения наводнений во всех изучаемых территориях. Также сравнительный анализ модельных гидрологических данных и социально-экономического ущерба от наводнений показали возможность применения моделирования к оценке потенциальной стоимости возможного ущерба. В завершении работы даны основные выводы и некоторые рекомендации относительно усовершенствования прогностических моделей и уменьшения ущерба от потенциальных наводнений.

1. Introduction

1.1. Objective

The aim of the work is to analyze the current trend of the frequency of occurrence of dangerous hydrological phenomena in the mountain regions of Europe and Australia to identify the causes of possible errors in forecasting and to give recommendations on optimization of forecasts and study ways to reduce the capacity of dangerous hydrological phenomena. Identify and analyze the areas most exposed to dangerous hydrological phenomena.

1.2. Tasks:

-To identify differences and common features in the processes of formation of floods in the mountain regions of Europe and Australia.

- To identify the most vulnerable catchment areas during the flood events, analyze future forecasts for these areas and reveal the peculiarities of the geographic location of the phenomena.

- To study the simulated hydrometeorological data and the measured data and make a comparative analysis of the results obtained.

- Compare and analyze future long-term changes in hydrometeorological parameters according to the most common scenarios of climate change.

- Identify and assess the relationship between flood forecasting and socio-economic impacts.

- Analyze the causes of inaccuracies in forecasting hazardous water events in mountain areas; provide recommendations for correcting forecasting techniques and offer ways of corrections small areas microclimate.

1.3. Relevance of the topic

A hydrological forecast is a preliminary assessment of the future characteristics of a hydrological phenomenon. Hydrological forecasts are needed to effectively manage water resources and mitigate the effects of natural hazards such as floods and droughts.

In connection with climate change, the number and scale of dangerous natural phenomena is rapidly increasing (AusGeo News June 2008 Issue No. 90). Dangerous hydrological phenomena in the mountains bring increasing damage to urbanized countries. The need for a more detailed study of natural processes in mountain areas is obvious. The urgency of this work is determined by the need to develop new methods for predicting and preventing dangerous hydrological phenomena.

1.4. The novelty of the research work

The novelty of scientific work is the comparison of completely different mountain areas in the European Alps and on the slopes of the Great Dividing Range in Australia. Not only the differences in physico-geographical conditions and the features of flood forecasting were studied, but also similar processes of formation of sudden floods were studied, which proves the possibility of sharing the experience of forecasting in individual situations.

In addition, a new direction in the work is an attempt to identify a correlation between the projected volume of water discharge in rivers and such socio-economic factors as the cost of flood damage. This is atypical for this kind of scientific work and illustrates the possibility of a more detailed analysis of such links between physiographic and socio-economic phenomena.

1.5. State of the Art

1.5.1. Flood emergency decision support systems

Flood emergency decision support systems have been used by flood emergency managers for decades. In the 1980s and 1990s these systems were usually data-driven and in the form of hard copy flood maps, graphs, tables and other documents. Advances in computer technology since the 1990s have enabled developers to extend the capabilities of these systems. Due to the limited computer speed at that time, these models were limited to point-based prediction; model predictions were limited to predicting the water level at several critical locations in the catchment area. The shortcomings of the point forecast were partially eliminated by interpolating point forecasts and using "pre-prepared" and historical flood maps as a surrogate for surface forecasting. This approach has a number of limitations. It has no accuracy, is limited to the maximum flooding surface and has no information about the timing of flooding and its temporal and spatial evolution throughout the flood event. Computer technology advancement and the development of GPUs (primarily used for fast-moving computer games) are now used to solve the governing differential equations of flood flow. This has significantly reduced solution computations times, thereby providing a unique opportunity for the developers to incorporate fully dynamic surface forecasting capacity into contemporary systems. A review of literature shows this capacity has not yet been fully integrated into flood emergency system (Ogde et al., 2001).

An important contribution of science and the engineering community is to help reduce the risk of floods, minimizing the likelihood that communities and infrastructure will be flooded and mitigate the negative consequences of flooding. More than 1,000 flood studies (Queensland Government, Office of the Queensland Chief Scientist) have been conducted in Australia, and scientists and engineers have developed a very sophisticated arsenal of flood forecasting and management techniques to reduce risk. However, there is still uncertainty about the many interacting factors that influence such natural phenomena, as these factors change over time.

Since 2003, the Institute for Environment and Sustainable Development (EC, Joint Research Center, Institute for Environment and Sustainability), located in Ispra, Italy, under the auspices of the Joint Research Center of the European Commission, in close cooperation with the hydrological and meteorological services of many European countries were developing a "European Flood Awareness System" (EFAS). The basis of the system is the hydrological model LISFLOOD, describing the runoff from the catchment basin and the current in the riverbed system. The model was developed specifically for large drainage basins and implemented using GIS technology. The main goal of the development of this system was to increase the lead-time of hydrological forecasts for large and transboundary river basins throughout Europe up to 3-10 days as well as increasing their reliability. To achieve this goal, weather forecast data are used, primarily on the intensity of precipitation, evaporation of moisture and average daily air temperature. The dominant trend in modern meteorological and then hydrological modeling was the combination of deterministic and stochastic approaches with the so-called systems of ensemble modeling (Ensemble prediction system, EPS) (National Oceanic and Atmospheric Administration and the United Nations Department of Economic and Social Affairs, 2004: Guidelines for Reducing Flood Losses). In the case of using the meteorological model, instead of one deterministic forecast, an entire ensemble of meteorological forecasts is issued, which allows taking into account the uncertainty of the model parameters, the incompleteness and uncertainty of the input data. Then this ensemble of meteorological information is used to model hydrological processes, resulting in a whole ensemble of hydrological situations. To date, the EFAS system has been put into operation and issues real flood warnings for a number of river basins in Europe. Based on the results of the use of the system in 2005-

2007 80% accuracy of forecasts of hazardous hydrological phenomena was reached, and the real lead-time averaged 5 days.

The scale of losses and damages from floods, which constitute a significant part of the adverse consequences of natural disasters, is constantly growing. Flood refers to a sharp increase in the level of water in a river, reservoir, reservoir, leading to flooding of significant areas of land and causing material damage (destruction of buildings and structures, human victims, changes and loss of ecosystems, destruction of relief forms).

It is enough simple to predict the scale of the flood, but to predict the time of its onset, even when there is sufficient data over a long period is quite difficult.

The accuracy of the forecast of flooding increases when reliable information is received on the amount and intensity of precipitation, the level of water in the river, the amount of water in the snow cover, changes in air temperature, the state of soil and grounds in certain areas and the catchment area in general, long-term weather forecasting, etc.

The forecast of floods can range from a few minutes in the conditions of rainfall in the upper reaches of small rivers to several days or more in the lower reaches of large rivers.

The integrated hydrological forecasting and response system includes the following elements, which must be linked together to ensure a reduction in flood losses: a) collection and transmission of data; (b) Hydrological forecasting and generation of forecast products; c) to bring forecasts to users; (d) Decision-making and support; e) actions taken by users.

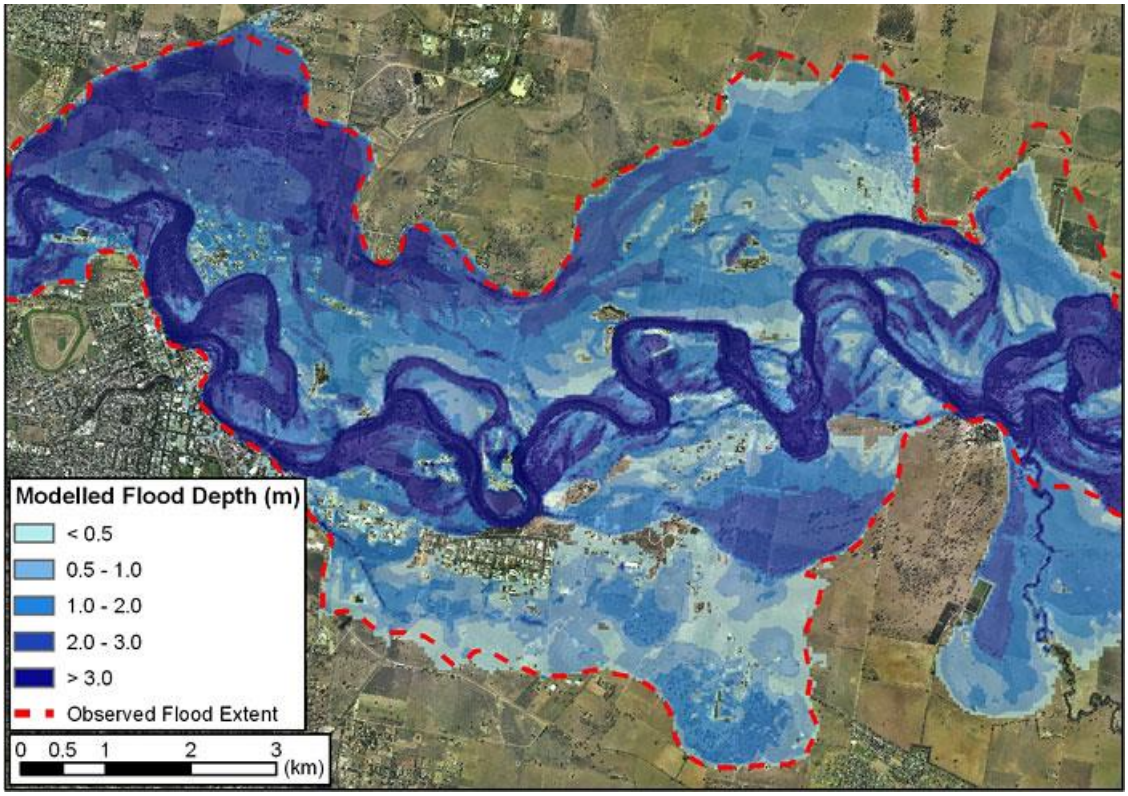

Figure 1. Post event comparison of flood extent modelled (predicted) by a floodplain hydraulic model (blue) and measured flood event (redline) in Wagga Wagga, NSW, 1974. While predictions are mostly very good, some variations can be observed between predicted and measured (observed) flooding, e.g. in the right hand side of the image. Courtesy of WMAwater.

It should be noted that any measured flood event would vary in some manner from the theoretical events from floodplain computer models (Figure 1). Such variations are primarily due to differences in the rainfall pattern; along with other factors such as how wet the catchment was before the event, and whether the storm center was over the lower or catchment central reaches.

In some countries, such as the United Kingdom, Bangladesh and Papua New Guinea, flood forecasting and prevention systems are complex and involve a relatively large number of institutions. On the contrary, Russia, Iceland, some Eastern European countries and others combine hydrological and meteorological services.

In Australia, for forecasting and preventing floods, the responsible Bureau of Meteorology. In addition to statistical models relating upstream peak river heights to downstream river heights, the main rainfall-runoff modeling tool for hydrologists of Bureau is the event-based Unified River Basin Simulator (URBS) model.

A typical flood forecasting process is shown in Figure 2. A flood forecasting process starts from the calculation start time to the calculation end time. The forecast start time is the start point of flood forecasting and is usually chosen after the main peak rainfall has appeared. The warm-up period is the period between the calculations begin time and the forecast start time. The measured flow is known during the warm-up period. Steady period, in which there is only slightly small rainfall, is the period from the calculation start time to the beginning of flood drastic rising (rising time) within the warm-up period. During the steady period, the main peak rainfall has not appeared, and the hydrograph is relatively flat.

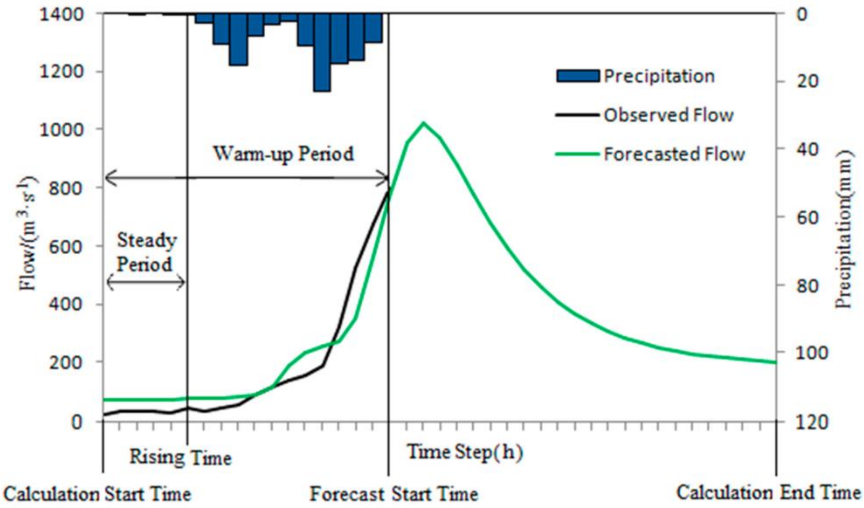

Figure 2. Typical flood forecasting process.

Because the rainfall is very little during the steady period, the forecasted flow is mainly affected by the initial state variables, and the accuracy of the forecasted flow can significantly reflect the accuracy of the initial state variables. Therefore, the forecasted and measured flows during the steady period can be used as the input of automatic optimization algorithm to correct the initial state variables. Since the initial state variables have continuous and systematic impacts on the flood forecasting, when the steady period obtains good simulation results, the initial state variables can be considered accurate. That is, when forecasting results are good in steady period, the forecasting results are also usually more reliable in the whole flood event.

The goal of flood warning is to help flood management agencies and the members of flood prone communities to understand the nature of developing floods so that they can take action to mitigate their effects. The purpose of a flood warning is to provide advice on impending flooding so people can take action to minimise its negative impacts. This will involve some people taking action on their own behalf and others doing so as part of agency responsibilities. A flood warning system is a set of connected activities (or elements) designed to achieve this purpose (Barrett, 1999).

This concept (illustrated in Figure 3) has been developed to describe the full range of elements that must be developed if flood-warning services are to be applied effectively.

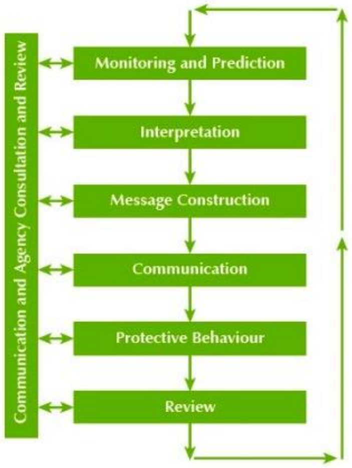

Figure 3. The components of the Total Flood Warning System (Australian Emergency Manual Series, Manual 21 Flood Warning, Australian Government 2009)

At its simplest, an effective flood warning system can be defined as having six components:

1. Monitoring and prediction: detecting environmental conditions that lead to flooding, and predicting river levels during the flood;

2. Interpretation: identifying in advance the impacts of the predicted flood levels on communities at risk;

3. Message construction: devising the content of the message that will warn people of impending flooding;

4. Communication: disseminating warning information in a timely fashion to people and organisations likely to be affected by the flood;

5. Protective Response: generating appropriate and timely actions and behaviors from the agencies involved and from the threatened community;

6. Review: examining the various aspects of the system with a view to improving its performance (Mogil et al., 1978).

1.5.2. Flood types

A flood is a land overflow of water that is usually dry. The European Union Floods Directive defines a flood as a covering by water of land not normally covered by water.

Inland flooding is the technical name for ordinary flooding that occurs in inland areas. Flash flooding, river flooding, and pretty much every type of flooding except coastal can be categorized as an inland flood.

Types of floods in mountainous areas:

Flash floods are caused by heavy rain or the sudden release of water over a short period. The name "flash" refers to their fast occurrence (typically within minutes to hours after the heavy rain event) and to their raging torrents of water that move with great speed. While the majority of flash floods are triggered by torrential rain falling within a short amount of time (like during intense thunderstorms), they can also occur even if no rain has fallen. The sudden release of water from levee and dam breaks or by a debris or ice jam can all lead to flash flooding. Because of their sudden onset, flash floods tend to be thought of as more dangerous than ordinary floods.

River flooding occurs when water levels in rivers, lakes, and streams rise and overflow onto the surrounding banks, shores, and neighboring land. The water level rise could be due to excessive rain from cyclones, snowmelt, or ice jams.

Australian Meteorology Bureau uses a three-tiered classification scheme that defines flooding as minor, moderate or major at key river height stations. Each classification is defined by the water level that causes certain impacts upstream and downstream of the station. These levels have been determined based on standard descriptions of flood effects, historical data and relevant local information.

The main types of river flooding:

Minor flooding. Causes inconvenience. Low-lying areas next to watercourses are inundated. Minor roads may be closed and low-level bridges submerged. In urban areas, inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths. In rural areas, removal of stock and equipment may be required.

Moderate flooding. In addition to the above, the area of inundation is more substantial. Main traffic routes may be affected. Some buildings may be affected above the floor level. Evacuation of flood-affected areas may be required. In rural areas, removal of stock is required.

Major flooding. In addition to the above, extensive rural areas and/or urban areas are inundated. Many buildings may be affected above the floor level. Properties and towns are likely to be isolated and major rail and traffic routes closed. Evacuation of flood-affected areas may be required. Utility services may be impacted.

Reporting or alert level. Water level rises to this level may cause the isolation of stock in very low-lying areas. Typically below the minor flood class level, this is the level at which a river alert is issued (where available).

Urban floods. Urban flooding occurs when there is a lack of drainage in an urban (city) area. Urban flooding is the inundation of land or property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers. Although sometimes triggered by events such as flash flooding or snowmelt, urban flooding is a condition, characterized by its repetitive and systemic impacts on communities that can happen regardless of whether or not affected communities are located within designated floodplains or near any body of water.

Ice jam flooding. In cold temperatures, bodies of water are often frozen. Heavy precipitation can cause chunks of ice to push together and create a dam in what is known as ice jam flooding. Behind the dam, water begins to pile up, spilling over to the plains nearby. Eventually, the wall of ice breaks, and fast-moving water rushes downstream much like a conventional flash flood, destroying objects in its path. The water carries huge chunks of ice, which can increase damage to surrounding structures.

Engineering issues. Manmade objects may cause flooding as well. A weakly constructed dam could receive a substantive battering than it was designed for and give way, creating a flash flood in the regions downstream.

1.5.3. Features of occurrence and prediction of flood events in Australia.

Even if nowhere is entirely safe from flooding, the risk varies greatly from region to region in Australia. Major loss occurrences are to be expected in Queensland and along the entire east of the country.

Apart from the Murray-Darling basin, there is no major river system in Australia. That is why river floods often behave in a similar way to flash floods, providing little or no advance warning. The flood wave in the Brisbane River in 2011 also rose very rapidly. Similar events are possible on nearly all Australian rivers, because they generally run a short route to the sea and have very few tributaries, allowing flood waves to approach quickly and suddenly (Sweeney, 1992).

The flooding of rivers following heavy rainfall is the most common form of flooding in Australia. Flooding of rivers in inland areas of central and western New South Wales and Queensland, as well as parts of Western Australia, can spread for thousands of square kilometers and may last for weeks or even months. In hilly or mountainous areas of these inland rivers, as well as in rivers draining to the coast, flooding can occur more quickly. As these rivers are steeper, flooding often lasts for only one to two days. Flash flooding usually results from relatively short intense bursts of rainfall, commonly from thunderstorms. This flooding can occur in any part of Australia, but is a particularly serious problem in urban areas where drainage systems may not cope and in very small creeks and streams. Flash floods tend to be local and it is difficult to provide effective warning because of their rapid onset (Stern, 2008).

New technologies are available, but not widely used in Australia, for providing near real-time mapping and delivery of forecast of flood inundation extent on the internet. These technologies use accurate ground-elevation data, robust floodplain hydraulic models, and new spatial information technology and internet map-serving software. Adoption of the technologies would significantly enhance the value of flood forecasts in Australia.

Flash floods are difficult to forecast, although technologies are available and used for forecasting. These technologies are generally based on monitoring of rainfall using rain gauges and radar images, high resolution rainfall forecasts for the next few hours, understanding of the catchment condition (how much rainfall will run off) and understanding of the local drainage systems (how much water is needed to cause a flood). As flash flood forecasts improve in accuracy and are integrated with communication and response systems over time, they can become highly valuable.

The BoM (Bureau of Meteorology) regularly issues forecasts of rainfall and temperature for the coming three months. The prospect of a wet season would lead to an increased chance of flooding, so forecasting seasonal rainfall can help alert us of flood risk. The high variability of rainfall across most of Australia from one year to another is largely the result of the El Niño – Southern Oscillation (Dutta et al., 2006).

Computer models are used to predict the development of the La Niña events that are often associated with heavy rains. However, seasonal forecasts are not highly accurate, and are expressed only in probabilistic terms – i.e. percentage chance of occurrence. For example, Queensland may have low rainfall on some occasions even in very strong La Niña events (Drosdowsky, Chambers, 2001).

Nevertheless, such forecasts have been demonstrated to be useful for industries such as agriculture, water resources and finance, indicating that the rainfall forecasts may also be useful for forecasting seasons with an increased chance of flooding.

In December 2010, the BoM commenced a seasonal streamflow (water discharge) forecasting service. This service provides forecasts of probabilities of total flow exceeding various volumes in the coming three months. The forecasts are also based on computer models; taking into account how wet or dry the catchments are at the start of the season as well as the climate. Although forecasts of floods are not directly made at the seasonal time scale, it is reasonable to expect an increased chance of flooding when total water discharge volume in the next season is forecast to be high.

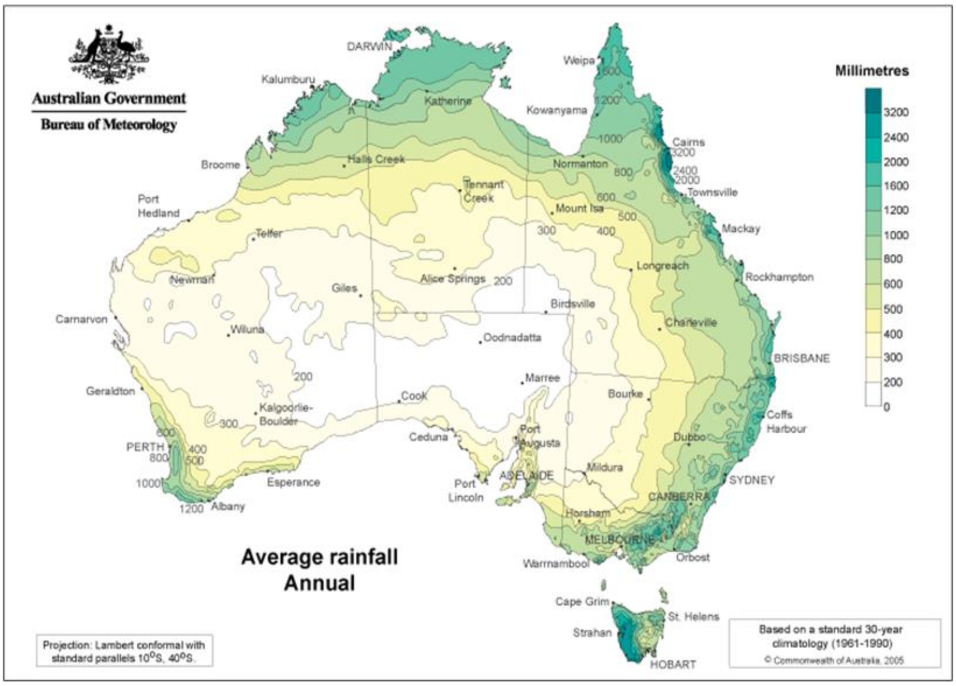

Figure 4. Average annual precipitation in Australia

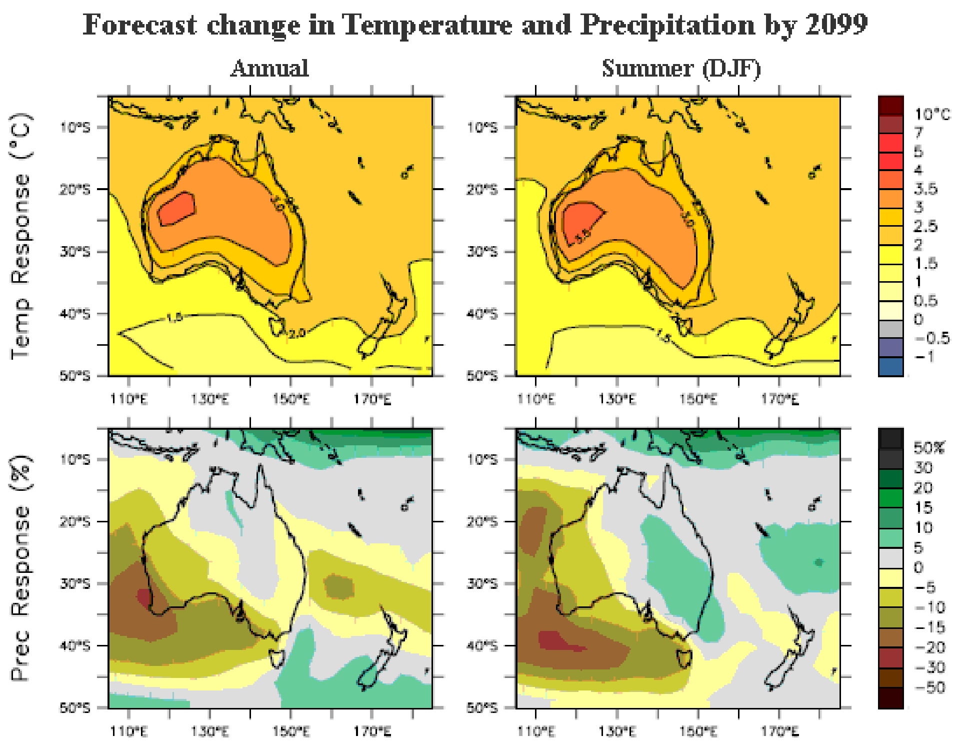

Figure 5. Average temperature and precipitation changes over Australia and New Zealand from the 21 climate models used to formulate the 2007 IPCC climate change report (A1B scenario). Annual mean and summertime (December-January-February) changes are plotted for the period 1980-1999 vs. 2080-2099. Image credit: 2007 IPCC report, section 11, "Regional Climate projections".

1.5.4. Features of occurrence and prediction of flood events in Alpine region of Europe.

Flood prediction in Alpine regions is a challenging task due to complex, physical interactions, including spatially and temporally variable meteorological processes as well as varied runoff contributions from rain and snowmelt. Aggregating such processes into a forecasting model brings uncertainties to all components of the flood forecasting chain (e.g., inputs, model structure). The nonlinear nature of models and the correlation of errors make uncertainty quantification and disaggregation a difficult task in hydrology. Despite much research, proper means of characterizing mountain floods is still poorly understood, and as a result, significant, comprehensive efforts have been made to quantify uncertainties of flood predictions in Alpine areas (Nicholls, 2001).

One of the most influential processes is orography whose effects are characterized by a rapid decrease of atmospheric moisture with altitude combined with a rain shadow effect on the leeside of mountains.

These effects are produced by the forced mechanical lifting of air over mountains, resulting in cooling of the air column, condensation and increasing precipitation with altitude while progressive warming and drying occurs on leeward sides. Such processes must be considered in flood modeling because the effective terrain elevation combined with synoptic scale meteorological processes have been proven to be highly correlated with the high precipitation intensities associated with mountain floods. The direction of synoptic-scale flow often dictates patterns of precipitation accumulation. Similarly, strong wind effects result in high spatial variability of snow accumulation (Shi, Dozier and Rott, 1994).

Snow cover in Alpine regions produces particular hydrologic situations; snow pack densities evolve due to freezing (re-freezing) and thawing or melting mechanisms. The dynamics of glacier retreat and re-freezing greatly impacts the accumulation of snow on glaciers and the melting of snow and ice. In addition, the input of latent heat into the snowpack during rainfall events causes rain-on-snow events to exacerbate flood damage (Anderson, 1973).

Hydraulic structures in Alpine regions also add to the complexity of modeling hydrologic processes for flood prediction. Particular to Alpine regions in Europe, runoff regimes are dominated by water capture for hydropower operations. For example, in the Swiss Alps, water is commonly captured at the headwaters, capitalizing on snow and ice melt and placed in storage lakes. Discharge from the lakes is either passed through hydropower turbines where it is returned to lower parts of the rivers or pumped back up to feed hydropower plants. Levels of the storage lakes depend on the economic incentive to store or produce energy. In the Upper Rhone River basin, which generates 50% of Swiss electricity, 38% of the rivers are affected by hydropower. To add to the challenge of modeling runoff flows, hydropower discharge data is typically daily (thereby not evident for flood modeling on hourly timescales) and day to day reservoir management is generally unknown due to confidential hydropower operations by private companies.

For calibration and data assimilation purposes, measured data are used to update hydrological models. A primary challenge in mountainous regions is the lack of measurement stations, particularly above 2000 m. Because gauged networks are relatively sparse at high altitudes, it is necessary to interpolate between meteorological stations to extend the limited measurement data to vast unmeasured, spatial areas. Interpolation is generally implemented at a resolution where physical hydrological processes are valid and not overly generalized. The difficulty of interpolation is how to maintain spatial and temporal correlations with minimum error while considering the influential effects of altitude and orography.

The interpolation of input temperature is also particularly critical in Alpine areas. To produce correct snowmelt volumes it is necessary to accurately estimating non-stationary temperature distributions with elevation. Another complexity for Alpine hydrological models is the partitioning between rain and snow. However, the spatial variability of snow cover can be very high due to the orientation of winds, different climatic situations and continental versus oceanic forcing.

2. Material and methods

2.1. Short characteristics of the study areas

2.1.1. Catchments in the Alps.

The Aare is a tributary of the High Rhine and the longest river that both rises and ends entirely within Switzerland (Figure 6). The Aare rises in the great Aargletschers (Aare Glaciers) of the Bernese Alps, in the canton of Bern and west of the Grimsel Pass. The Finsteraargletscher and Lauteraargletscher come together to form the Unteraargletscher (Lower Aar Glacier), which is the main source of water for the Grimselsee (Lake of Grimsel). The Oberaargletscher (Upper Aar Glacier) feeds the Oberaarsee, which also flows into the Grimselsee.

Right after Innertkirchen its first major tributary, the Gamderwasser, joins it. Less than 1 kilometer (0.62 mi) later, the river carves through a limestone ridge in the Aare Gorg. It is here that the Aare proves itself more than just a river, as it attracts thousands of tourists annually to the causeways through the gorge. A little past Meiringen, near Brienz, the river expands into Lake Brienz. Near the west end of the lake, it indirectly receives its first important tributary, the Lütschine, by the Lake of Brienz. It then runs across the swampy plain of the Bödeli between Interlaken and Unterseen before flowing into Lake Thun.

The Rhône is one of the major rivers of Europe and has twice the average discharge of the Loire (which is the longest French river), rising in the Rhône Glacier in the Swiss Alps at the far eastern end of the Swiss canton of Valais (Figure 6). The Rhône rises as an effluent of the Rhône Glacier in the Valais, in the Swiss Alps, at an altitude of approximately 2,208 meters (7,244 ft). From there it flows south through Gletsch and the Goms, the uppermost, valley region of the Valais before Brig. Shortly before reaching Brig, it receives the waters of the Massa from the Aletsch Glacier. It flows onward through the valley that bears its name and runs initially in a westerly direction about thirty kilometers to Leuk, then southwest about fifty kilometers to Martigny.

Down as far as Brig, the Rhône is a torrent; it then becomes a great mountain river running southwest through a glacier valley. Between Brig and Martigny, it collects waters mostly from the valleys of the Pennine Alps to the south, whose rivers originate from the large glaciers of the massifs of Monte Rosa, Dom, and Grand Combin.

The Sava is a river in Central and Southeastern Europe, a right tributary of the Danube (Figure 6). The Sava River is formed from the Sava Dolinka and the Sava Bohinjka headwaters in northwest Slovenia. The Sava Bohinjka originates in Ribčev Laz, at the confluence of the Jezernica, a short watercourse flowing out from Lake Bohinj and the Mostnica River. In some sources, the Jezernica has been defined as a part of the Sava Bohinjka, specifying the latter as flowing directly out of the lake. Another group of sources includes Savica, rising at the southern flank of Triglav as the 78-metre Savica Falls, downstream from Triglav Lakes Valley, and flowing into the lake, as a part of the Sava Bohinjka. The watercourse flows 41 kilometers (25 miles)—including the length of the Savica — east to Radovljica, where it discharges into the Sava Dolinka. Downstream from the confluence, the river is referred to as the Sava.

2.1.2. Catchments in Australia.

The Brisbane River (indigenous name Maiwar) is the longest river in South East Queensland, Australia, and flows through the city of Brisbane, before emptying into Moreton Bay (Figure 7). Its chief tributaries are the Stanley and Bremer rivers and Lockyer Creek. The Brisbane River is navigable for steamers below Brisbane (about 15 miles [25 km]) and for small craft below Ipswich (50 miles [80 km]).

The river travels 344 km (214 mi) from Mount Stanley. The Wivenhoe Dam, forming Lake Wivenhoe, and the main water supply for Brisbane, dams the river. Historically, several catastrophic floods of the Brisbane River have occurred, notably in 1893 and 1974. Heavy rains in early 2011 caused the river to flood and to inundate several riverside communities, including large portions of Brisbane.

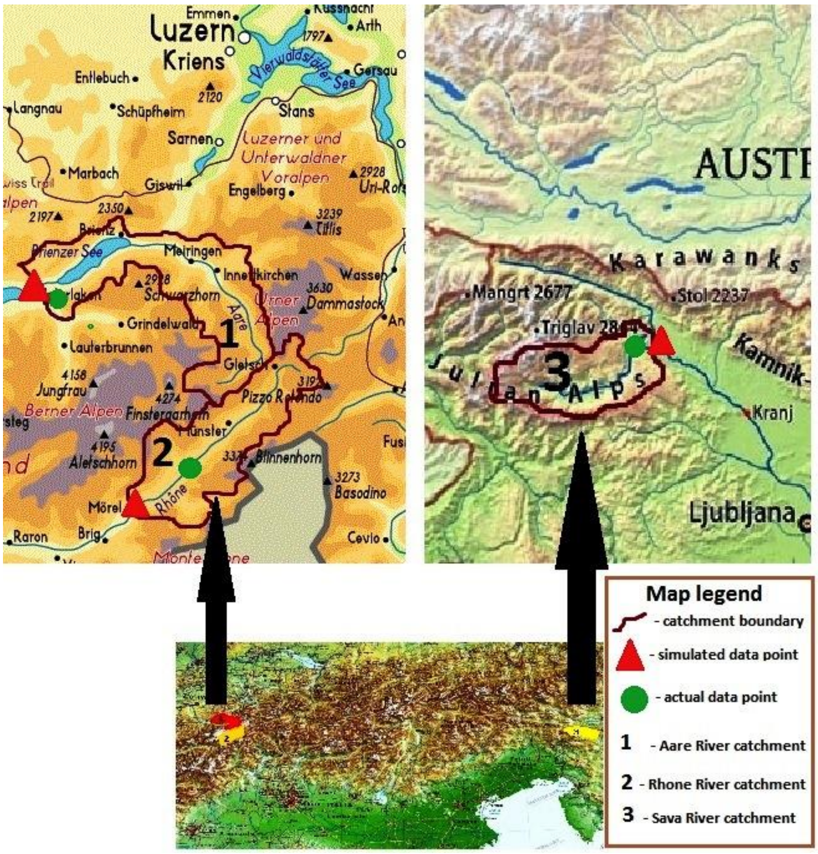

Figure 6. Maps of the main studied catchment basins in Alps

Figure 7. Map of the catchment basin of The Brisbane River

2.2. Main flood forecasting methods:

Flood forecasters rely heavily on real-time data about rainfall and river water levels as well as rainfall forecasts. A network of rain gauges (sometimes combined with radar images) are used to monitor rain that has fallen on the catchment. Water levels (i.e. river height) at stream gauging stations along the river are also measured. The forecasters then use hydrological computer models to work out how much rainfall will run off different parts of the catchment, how long it will take for runoff to reach the river, how long that water will take to travel from upstream to downstream, and how water from different tributaries converges in the river network.

Because rain that has fallen on a catchment takes time to travel to the outlet of the catchment, river flow downstream of the catchment within a certain period will largely be influenced by rain that has already fallen on the catchment and been observed. This means that the river flow forecast for this period will be reasonably accurate. River flow forecasts beyond this period will be less accurate as it is necessary to use rainfall forecasts.

If a critical dam operation is involved in a flood event, the forecasters communicate with dam operators. Decisions about releasing water from dams take into account forecasts about how much water will flow into the dam and assessments of how water releases may affect water levels downstream. In turn, flood forecasts for downstream areas take into account water release decisions.

Forecasts of river water level are most useful when interpreted in terms of where the water is likely to spread beyond the river. Such interpretations may be provided to the public by local governments and emergency agencies, usually based on pre-prepared flood maps using historical flood data and in some cases floodplain hydraulic models.

The chance of a flood event can be described using a variety of terms. Floods are often defined according to their likelihood of occurring in any given year. The most commonly used definition in planning is the '1 in 100 year flood'. This refers to a flood level or peak that has a one in a hundred, or 1%, chance of being equaled or exceeded in any year. Similarly, a '1 in 200 year flood' has a one in two hundred, or 0.5%, chance of being equaled or exceeded in any one year.

Other terms that express the same idea, such as 1% annual exceedance probability (or 1% AEP), are preferred because they avoid the common misconception that a '1 in 100 year flood', for example, can only occur once every 100 years; or that you are 'safe' for another 100 years after you experience such an event. For example, in Kempsey, NSW, major floods approaching the 1% AEP level occurred in 1949 and then again a year later in 1950.

In reality, the chance of experiencing different sized flood events in a given period can be estimated mathematically (see Table 1). If you lived for 70 years in a location that had a 1% chance of flooding in any one year (that is, it would only flood if a '1 in 100 year flood' occurred), then there would measuredly be a 50% chance, or one in two odds, of you experiencing at least one flood during that 70 year period. The way we calculate this is: 100% minus the chance of a flood not happening 70 times in a row, i.e. 0.5 = 1 - 0.9970.

Table 1. Probabilities of experiencing a given size flood once or more in a lifetime. Modified from Floodplain Development Manual: the management of flood liable land, NSW Government, 2005.

Chance of a flood of a particular size being exceeded in any one year	Chance of experiencing a flood in a 70 year period	
	at least once	at least twice
10% (1 in 10 odds)	99.9%	99.3%
5% (1 in 20 odds)	97.0%	86.4%
2% (1 in 50 odds)	75.3%	40.8%
1% (1 in 100 odds)	50.3%	15.6%
0.5% (1 in 200 odds)	29.5%	4.9%

The forecast of the hydrodynamic model is based on the initial state of the atmosphere from the data of meteorological observations. Further, the changes in pressure are calculated, which will occur after a short enough period, for example, after 10 minutes. This gives a new data set, which is used to calculate conditions through the next 10-minute interval.

This procedure is repeated until a pressure field is obtained for the forecast period. As the atmosphere is in constant motion, in order to determine the future weather at a given point, it is first of all necessary to know the characteristics of the air mass, which can move to the forecast point for the period of time that is intrinsic to the forecaster. In other words, it is necessary to know the weather not only in the forecast point, but also at a considerable distance from it. If we take the average wind speed of 40 km / h, it is easy to calculate that for the forecast for the day this distance will be 1,200 km. In practice, it can be several thousand kilometers, because the wind speed on the roads can reach 100 km / h or more. As the forecast advance increases, the observation data collection zone increases, and for the forecast for 5-7 days it is necessary to have observational data from around the globe.

Monitoring of dangerous phenomena of a hydrometeorological character is one of the most globalized, since for a qualitative forecast some national data are insufficient. Space means of control are used mainly in the form of scanner surveys with equipment with a resolution of 30-35 m. Determination of the contours of flooding and its dynamics are possible by using the materials of space-based surveys.

The creation of a digital terrain model allows for clearer identification of areas that are threatened by flooding. All areas below the current average height of the water level are classified as high-risk areas, and special protective work is carried out in these areas. Thus, conducted land classifications allow not only to reduce the damage caused by flooding, but also to estimate potential monetary losses in the event of the following floods. Understanding the chance of different sized floods occurring is important for managing flood risk.

The best method for calculating the chance of different sized floods occurring is statistical analysis of long-term flood records from stream gauging stations. Where a long-term flood record exists, and no significant changes have occurred to the catchment, a statistical technique known as flood frequency analysis can be used to determine the likelihood of floods of different sizes occurring at a specific site in the future. However, Australia's flood records do not extend far into the past, and flood events are highly variable, meaning there is still a level of uncertainty in defining such flood estimates. Climate change may also affect how much we can rely on past flood records.

Where sufficient flood records do not exist, or a very rare flood needs to be estimated, *rainfall based techniques* are used. These use statistical analyses of rainfall records, together with computer models based on the geographical characteristics (for example, catchment area, waterway length) of the region being studied, to determine the chance of different sized floods occurring. These models can be set up to take account of changes that affect runoff, such as new dams and urbanisation, but the computer models used to convert rainfall to runoff are not perfect, making rainfall techniques generally less reliable than the use of long-term flood records (Urbonas and Roesner, 1993).

The accuracy of climate and weather forecasts varies with lead-time, spatial scale (or size) of the region of interest, the weather or climate variable being forecast (for example, rain, thunderstorm), as well as with latitude. It is generally easier to forecast rainfall over a large area (for example, a large catchment) than local rainfall (for example, over a reservoir). This is because the intensity of any rain system varies on small spatial scales, but the variation is somewhat averaged out over a large area.

Rainfall forecasts can be used to extend the lead-time for flood forecasts. However, because forecasts of rainfall for specific locations and timing are not fully accurate, flood forecasts based on rainfall forecasts are often subject to significant uncertainty.

Statistical analysis of long-term records of floods and precipitation provides a forecast of peak water discharge at key points of the rivers. These predictions are translated into flood levels at any point of interest in the floodplain, by further computer models known as floodplain hydraulic models.

Floodplain hydraulic models are virtual representations of the river and its surrounding land, or floodplain. They incorporate things such as ground levels, roads, embankments and river sizes to estimate predicted flood flows. The output of the models includes representations of predicted flood levels and the predicted speed of water discharge.

2.3. "HYPE" model

To study prognostic models in the Alpine region, the resource capabilities of the online HYPE system were used. HYPE is a multipurpose model. Current operational uses include water forecasting in Europe today (WET, a real-time water information service), delivering forecast data to oceanography models, delivering a soil-water forecast for gardening companies and more. The model is also used for many research projects including as the main source of open data for both research experiments and production in the SWITCH-ON project, for European climate scenarios in the IMPACT2C and ECLISE projects, for seasonal forecasting in the EUPORIAS project and more. A separate pan-European model, EFAS-HYPE is currently being tested in the European Flood Awareness System (EFAS).

Using the information from "HYPE" database and with the help of calculations on the web site of this organization, the changes in the hydrometeorological parameters of the studied river basins were analyzed.

2.3.1. Scenarios of climate change developed by the IPCC

The calculations took into account changes in two of the four scenarios (RCP 4,5 and RCP 8,5) of climate change developed by the Intergovernmental Panel on Climate Change (IPCC), an organization created to assess the risk of global climate change caused by man-made factors (human actions). The most recent assessment report (Assessment Report 5 or AR5) was completed in 2014.

The report considers four scenarios in which the concentration of greenhouse gases by the year 2100 will reach 421 ppm (RCP2.6), 538 ppm (RCP4.5), 670 ppm (RCP6.0), and 936 ppm (RCP 8.5). The scenario RCP2.6 implies that the peak of greenhouse gas emissions will be in 2010-2020, after which there will be a decline. In the RCP4.5 scenario, it is assumed that the emission peak will occur around 2040 and RCP6.0 will be 2080. The RCP8.0 scenario assumes that emissions will continue to grow over the course of a century. The obtained projections of average temperature growth relative to the average values of the period 1986-2005 (Figure 8).

In the modeling parameters, manually the data of carbon dioxide content changes are entered, and based on these data the model calculates the change in temperature, precipitation and other meteorological parameters on a global scale and for individual territories.

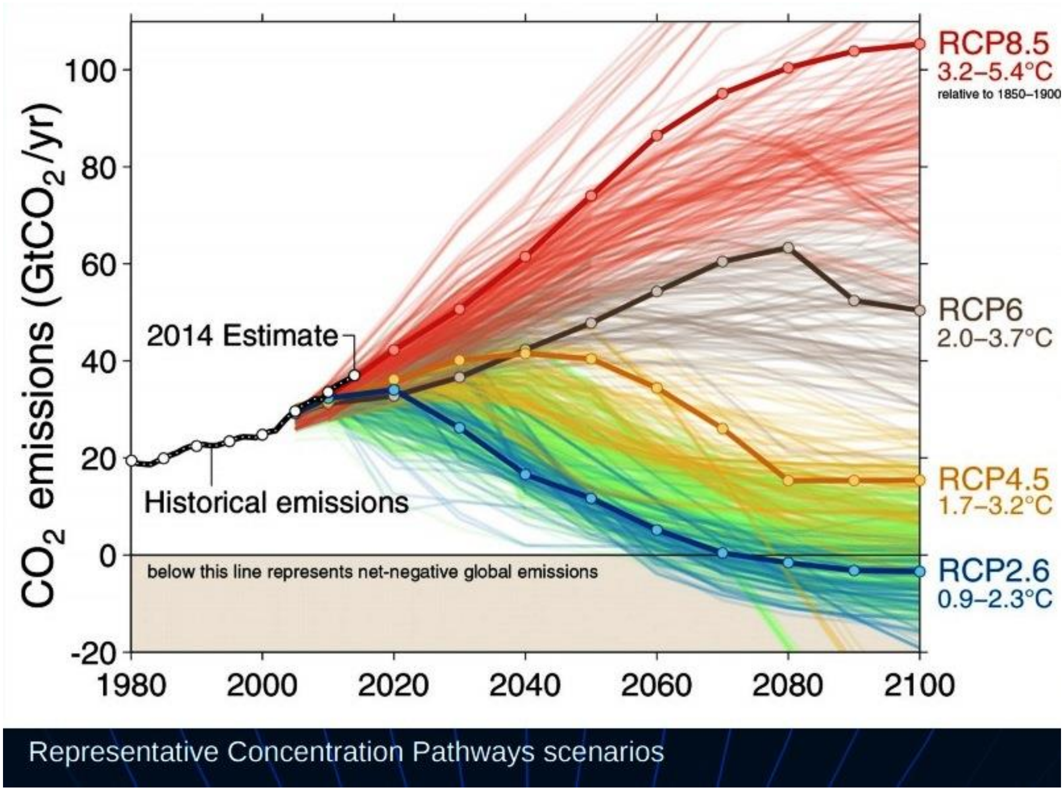

Figure 8. Global CO2 emission scenarios

Due to the different amount of carbon dioxide content in the atmosphere in models, the predicted increase in temperature is also different. If in the scenario 4.5, the temperature rises by 1.7 - 3.2 degrees per 100 years and stabilizes in the second half of the century, according to scenario 8.5 there is a constant temperature increase with the maximum level of 3.2 - 5.4 degrees during the century. It is because of the difference in temperature growth charts in the scenarios that there are differences in all other hydrometeorological parameters; however, the overall trend is generally the same. The predicted change in the amount of atmospheric precipitation according to both scenarios will rise for all the areas considered by 1-5% in the 2030s, up to 5-10% in the 2050s according to the maximum scenario (8.5) and up to 5-10% according to both scenarios in the 2080s years (Figure 23 in appendix). There is a direct correlation between the increase of temperature and the amount of precipitation increase. If we consider the neighboring lower river basins, it can be noted that the contrast of the moisture distribution increases. The most moistened slopes will receive even more rainfall in the future, while sufficiently dry areas will become even more arid. It is also worth mentioning that, according to this contrast trend, the duration will decrease, but the intensity of downpours and snowfalls will increase. That is why the risk of sudden floods will increase, even in relatively dry river basins.

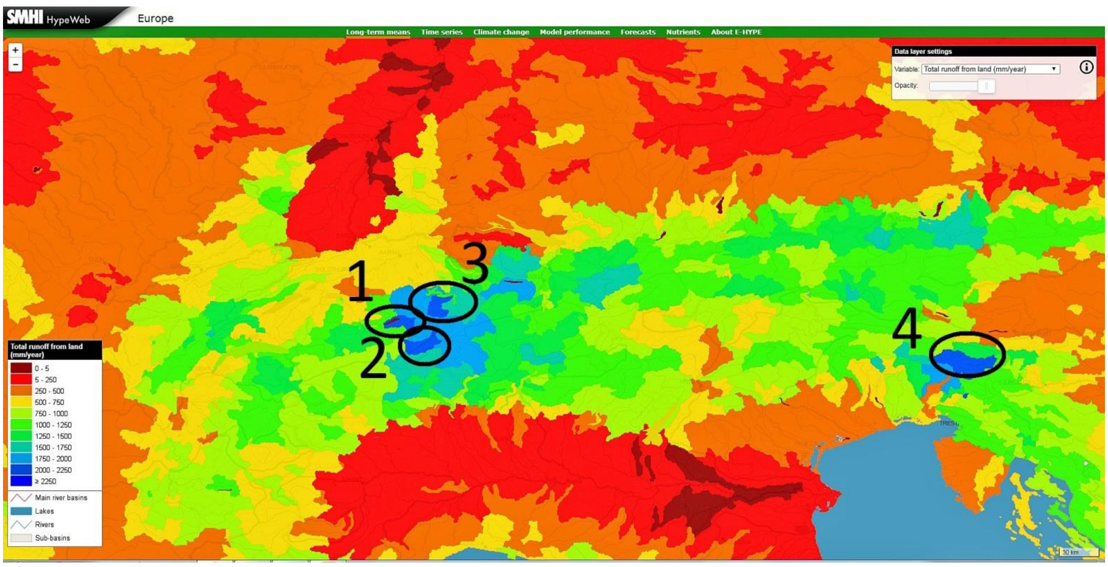

Figure 9. Basins with the highest total runoff from land (mm/year) (data provided by hypeweb.smhi.se)

At the next stage of the research, it was decided to select 4 river basins with the greatest risk of flood development and compare the simulated data for these basins with the measured data. When selecting swimming pools, parameters such as the amount of precipitation, humidification, total surface water runoff, the availability of an infrastructure potentially at risk of flooding, and the projected increase in the intensity of precipitation in the future were taken into account.

As a result of the calculations the highest total runoff from land (mm / year) 4 basins were identified using the data of the Regions with Hydrological Predictions for the Environment (HYPE) database and a pronounced correlation with the amount of precipitation was revealed. It these populated highlands of the Alps are most susceptible to flash floods that have occurred repeatedly throughout history, according to historical references of nearby cities.

The following basins were analyzed:

1. The upper reaches of the Aare River above Interlaken (Switzerland)
2. Upper reaches of the River Ron (Switzerland)
3. Upper reaches of the Melhaa River (Switzerland)
4. Upper reaches of the River Sava Bojinka (Slovenia)

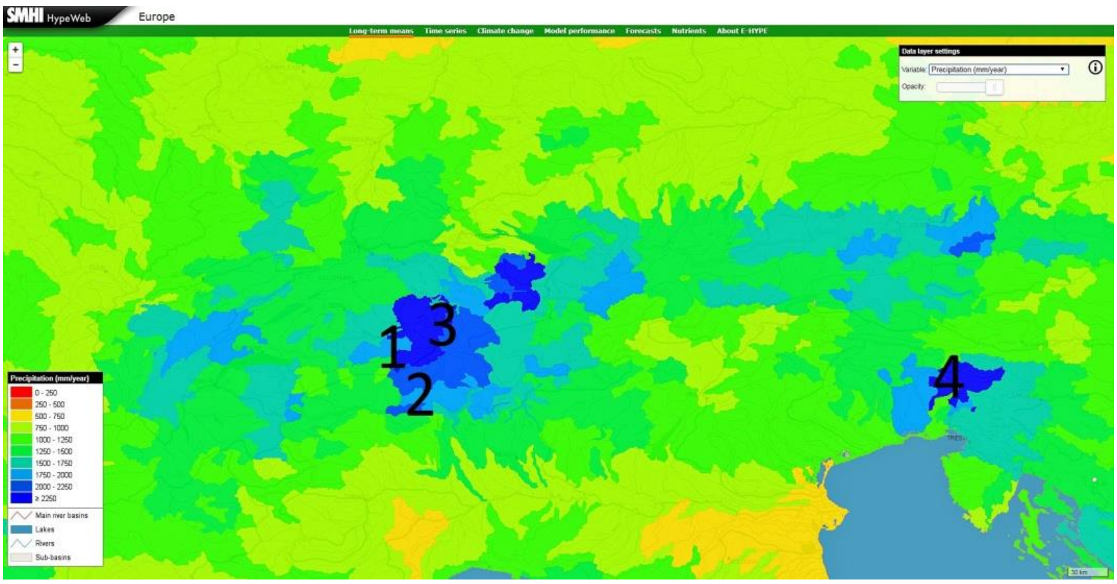

Figure 10. River basins with the highest amount of precipitation (data provided by hypeweb.smhi.se)

2.3.2. Comparison of hydrometeorological forecasts for the studied basins

According to the forecast for the next 60 years, the amount of precipitation, total runoff from the surface and the water discharge in the rivers in the specified basins will increase from 5 to 50% (Figures 13, 25 in appendix).

In addition, during the analysis of the database, a correlation was observed between the total runoff from the surface and the average snow depth and with the simulated evapotranspiration (Figures 11, 12 in appendix).

Comparing the graphs of changes in water discharge rates for individual years, it can be concluded that there are two main peaks: at the beginning and at the end of the warm season, as well as slightly lesser periods with increased water discharge in the rivers. The first peak is usually associated with the beginning of the melting of snow at high altitudes in the mountains and is observed in early June. The second peak is usually carried out in August-September and is associated with a peak of glacier melting activity against precipitation of atmospheric precipitation in the liquid phase. Analyzing the data of the graphs presented in (Figures 11 and Figures 14, 15 in appendix) and numerical data (Table 2), it was found almost complete coincidence of the calendar dates with the same trends in the water discharge in the rivers of the first three basins located in the highlands of Switzerland. While the river basin located in Slovenia is very weakly correlated with the sites in Switzerland.

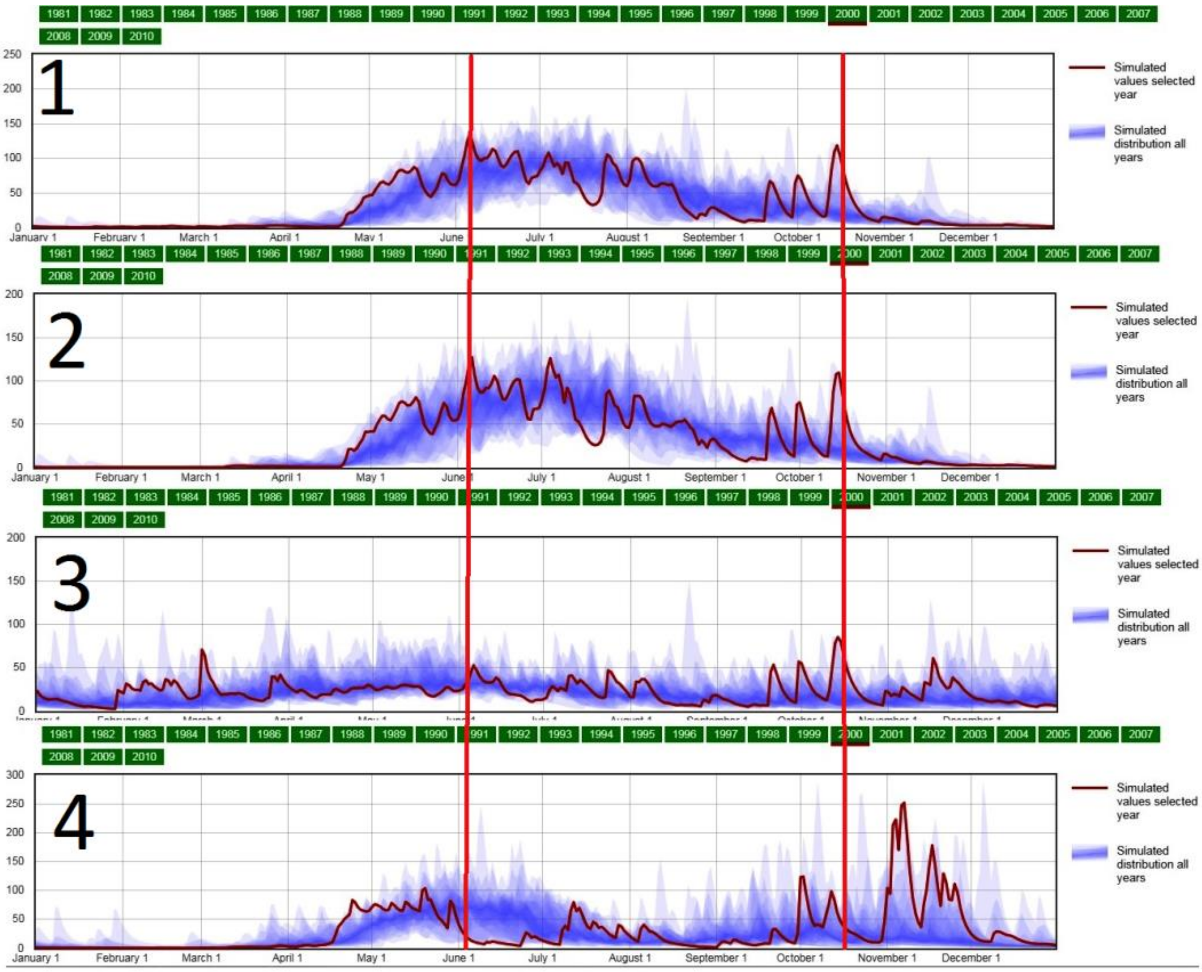

Figure 11. Comparison of water discharge peaks in the studied basins in 2000 (data provided by hypeweb.smhi.se)

The coincidence of many indicators in the first three basins is explained by the close geographic location of the objects to each other. Despite the difference in the exposure of the slopes and the diversity of the topography of the areas, there is approximately the same amount of precipitation and almost identical to the daily temperature variations at the same altitudes. This feature can simplify the methodology of flood forecasting for these areas, developing a forecast for one of the studied river basins, it can be successfully applied to neighboring territories making simple adjustments.

All additional calculation were made by using cartographic method, statistical method, satellite method (analyzing satellite images), historical method, expert evaluation method, prediction methods, analysis and synthesis method.

3. Results

3.1. Analysis of the differences in physico-geographical characteristics of flood formation processes in the Alps and the mountainous territories of Australia.

The main differences between the Alpine mountain system and the Great Dividing Range in Australia are in climate and altitude above sea level. In the Alps, the main difficulties in calculating the probability of floods are the lack of meteorological data at high altitudes, problems in accurately estimating orographic precipitation, and a complex combination of the interaction of the solid and liquid phases of water. In Australia, where the mountain system lower and snow cover does not play such a significant role, the main problem is the considerable inaccuracy in weather forecasts in the tropical monsoon climate in comparison with the forecasts in the temperate climate (Ebert et al., 2011). In connection with the increased instability of the atmosphere in the tropical latitudes during the monsoon period, the accuracy of weather forecasts falls sharply. The most uncertain are the forecasts of the amount of precipitation and their spatial distribution. This feature, combined with the fact that all the rivers on the east coast are very short and mostly mountainous, explains the complexity of flood forecasting. The limiting factor is also the high rate of development of hydrological phenomena. From the onset of precipitation to the onset of flooding, only a few hours can pass. Most often, during the monsoon period, floods occurring on the east coast in Queensland, which causes great damage to the economy due to the high population density in these areas. It should be noted that the highest part of the Great Dividing Range, the Snowy Mountains, is located in the south of the continent in a cooler climate and is affected by the snow cover during the winter months. However, due to the distance from the influence of monsoons, the territory has a more even distribution of precipitation and is less prone to flooding, although sometimes in snowy periods, there is an exceptionally rare phenomenon for Australia - avalanches.

When comparing the hydrological charts for the Sava River in the Alps and the Brisbane River on the east coast of Australia in the most typical year for them, there are clear differences in the distribution of water discharge throughout the year. If for the Alpine rivers, the prevailing type of food is glacial-rain, then for tropical Australia, there is a pronounced rainfall type of food with a maximum water discharge Q max during the rainy season from December to March. For example, on the Sava River, the graph displays numerous peaks of water discharge during the warm period; these peaks appear with the beginning of snowmelt, intensifying during the maximum melting of glaciers and repeating during periods of autumn rains. On the Brisbane River, peak water costs fall on periods of heavy rainfall during the monsoon period, but also occasionally occur in the winter in the event of frontal precipitation. In addition, a very high consumption of indicators is observed in the Brisbane River from year to year, and the water discharge in wet years is several tens of times higher than the dry years. In contrast to the eastern coast of Australia, the Alpine rivers are more stable and the difference in runoff in humid and dry years varies insignificantly, usually by no more than 10%.

Despite the widespread tendency to increase the contrast of the climate and in connection with this increase in the risks of sudden floods, now, the scenarios of hydrometeorological changes in the Alpine region have been calculated with the greatest accuracy. That is why the author decided to concentrate research in the Alpine region and to analyze the justification of hydrological forecasts by comparing them with measured data.

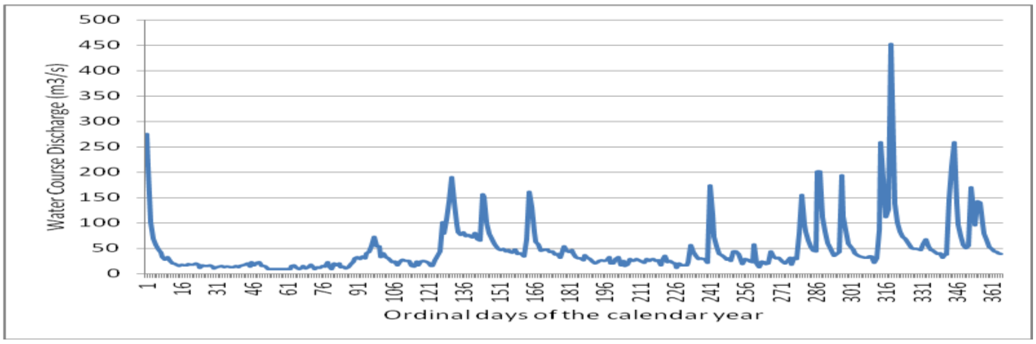

Figure 12. Water discharge of the Sava River, daily data for the observation period from 1 January to 31 December 1982

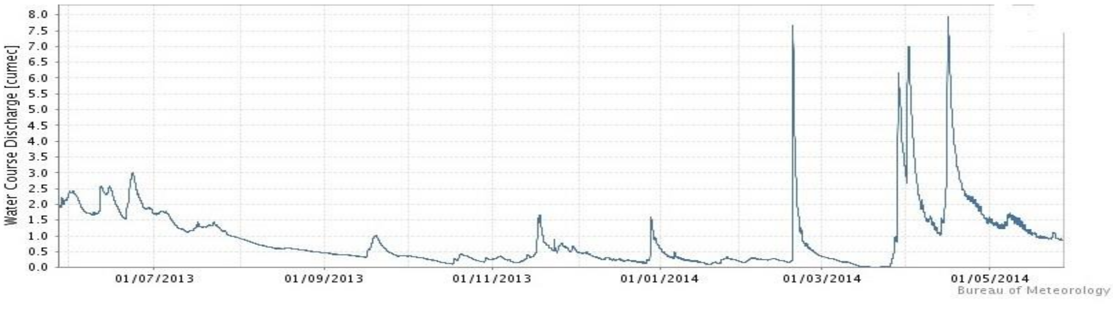

Figure 13. Watercourse discharge of the Brisbane River at Linville, daily data for the observation period from June 1, 2013 to May 31, 2014 (provided by water data online)

3.2. Comparison modeled and measured data

Based on the measured data obtained with the help of the European Global Runoff Data Center, daily data for the period from 1981 to 2010 for the Aare, Rhône and Sava Rivers were analyzed (Figures 3-10 in appendix). According to the river, long-term hydrological charts and trend lines were built. Despite the undeniable climatic changes over the previous thirty years, the trend of changes could not be identified (Figures 1, 2 in appendix). How can be explained as the insufficient accuracy of measured data and natural causes? For example, in some parts of river basins the accelerated melting of glaciers can compensate for the decrease in precipitation, and in other parts, increasing evaporation due to climate warming can compensate for the increase in precipitation, which generally allows the river flow to remain generally stable, despite significant changes in hydrometeorological conditions.

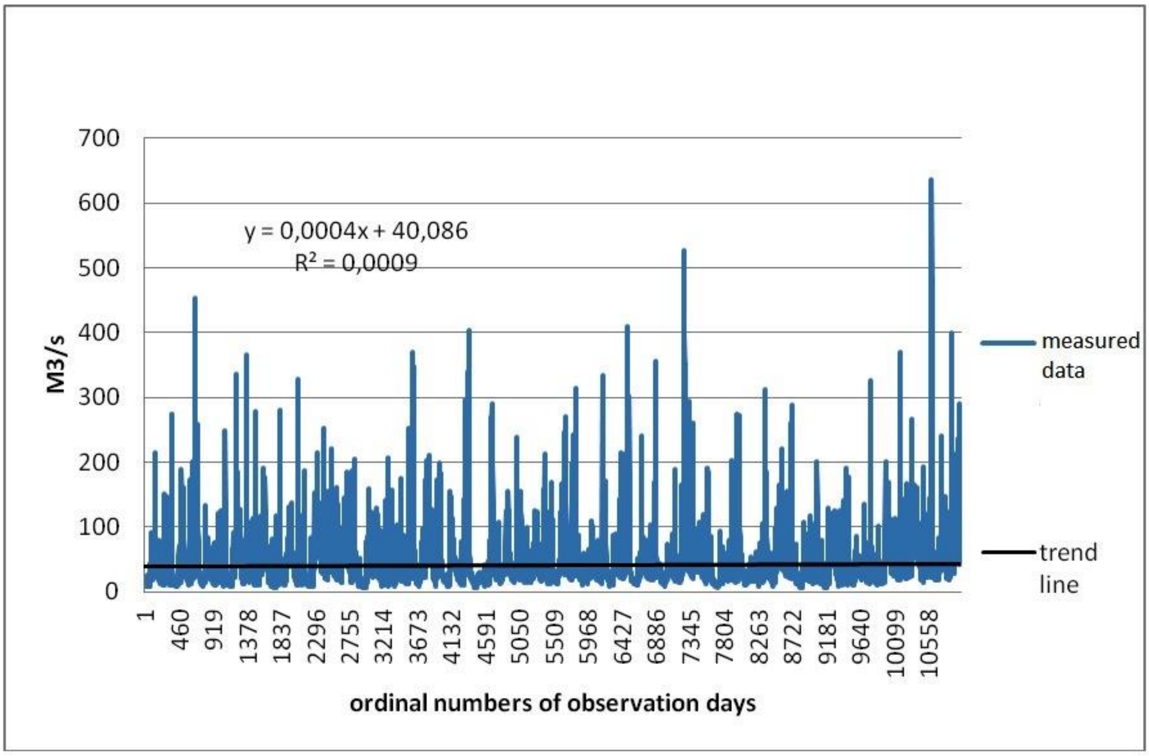

Figure 14.Trend of changes in the average daily water discharge of the Sava River for the period from 1981 to 2010. y = 0.0004x + 40.086 R^2 = 0.0009 (insignificant trend)

Based on a comparison of the daily water discharge data for the period from 1981 to 2010, the maximum and minimum daily values for the three studied river basins were identified in the Excel program. The largest water discharge differentials are typical for the

Sava River where, with an average water discharge of 42 m3/s, in the periods of floods, the values increased to 636 m3/s, and in dry periods fell to 5 m3/s (Table 2). It should be noted that for this river, a significant correlation was found between the simulated data and the measured data (Table2). Large water discharge differences are noted in the upper reaches of the Aare River 204 and 2 m3/s, which, with a low correlation between the simulated data and the measured (0.2), can create a threat of unpredictable flooding. In spite of the relatively low maximum water discharge (18 m3/s) and the good correlation of the simulated and measured data (0.8) in the Rhône basin, floods that caused considerable material damage were repeatedly noted.

Table 2. Maximum and minimum daily water discharge for the period from 1981 to 2010

Number and name of catchment	Q max m3/s /date	Q min m3/s / date	Average m3/s	Observation period (daily data)	Correlation between modeled and observed data
1. upstream of the Aare River	204.3 / 22.08.2005	1.9 / 3.02.2010	19.1	01.01.1981 – 31.12.2010	0.2
2. upstream of the Rhone River	18.3 / 24.08.1987	0.1 / 20.02.2006	2.9	01.01.1981 – 31.12.2010	0.8
3. upstream of the Sava River	635.8 / 25.12.2009	5.6 / 02.02.1989	42	01.01.1981 – 31.12.2010	0.6

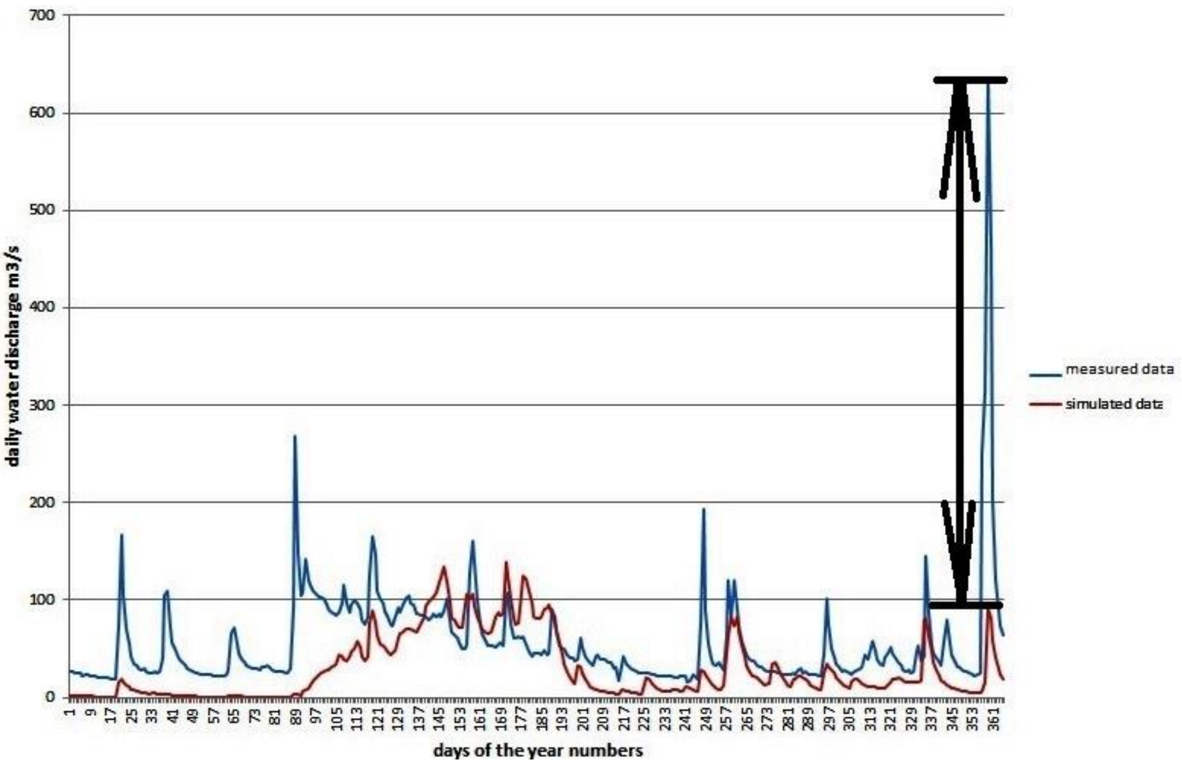

Figure 15. Daily water discharge graph in the upper reaches of the Sava River.2009 wet year (average water discharge 56 m3/s). The arrow on the graph shows the value of underestimation of the peak values of the river discharge.

Table 3. Comparison of simulated and measured data of daily water discharge peaks

Number and name of catchment	Dry year				Wet year			
	Simulated data M3/s	Measured data M3/s	Underestimation (d) M3/s	Underestimation (d) %	Simulated data M3/s	Measured data M3/s	Underestimation (d) M3/s	Underestimation (d) %
1.The Aare River	132	9	-123	93.2	125	15	-110	88
2.The Rhone River	53	204	151	74	27	100	73	73
3.The Sava River	101	207	106	51	82	635	553	87

Because of the comparison and analysis of the simulated and measured water discharge data for the three catchment areas, significant inaccuracies in the simulated data were identified (Tables 1, 2 in appendix). Despite the significant correlation between the two series of data (Table 2), it was noted that the values are close to real only on days with low water consumption. On days with a maximum daily water discharge, there is often an underestimation of peak values by more than 10 times (Table 3). Analyzing water discharge graphs (Figures 2-10 in the appendix), it becomes obvious that this prediction model is possible for use in the upper Sava river. However, the calculation of the peak values is required, without such an adjustment, an accurate calculation of the probability of floods is impossible. As for the other two basins, the possibility of using simulated data is very doubtful, since it almost never reflects the measured flow of water, significantly overstates (the Aare River) or greatly underestimates real values (the Rhone River). There is also a noticeable time shift in the calculations, the simulated peak values are often either delayed or vice versa given prematurely, which is well traced on all graphs. In addition to the imperfection of the data calculation model, the reason for the data mismatch may also be the difference in the location of the calculation points for the simulated data and the points of obtaining the measured data (see Figure 6). As a result, we can say that the river flow-forecasting model works well only for individual catchment areas and periods. In order to seriously using this model for flood forecasting, it is necessary to improve the calculation systems, especially for peak water discharges.

So, as a result of the analysis, it was determined that from the ones chosen for the study of the Alpine basins only for the Sava River the simulation works is acceptable, although this river has the greatest fluctuations in water discharge during the year. Working with long-term indicators of water discharge in the Sava River, there was no significant trend, but the construction of the integral curve allowed to see some features of the distribution of water consumption by years. Up to the mid-1990s, indicators exceeding the average values prevailed, and after years began to prevail with a lower water consumption. It can be assumed that a large cycle of fluctuations in water content is about 30 years or slightly more, but to confirm this hypothesis, data for a larger gap than available are required. Against the backdrop of large fluctuations, smaller and less significant cycles of about 10 years can be traced, which we can observe on the graph of the deviations of the water discharge from the mean multiyear values. As can be seen in the graph in recent years, the integral curve rises sharply, which means an increase in average water discharge rates. In this regard, it can be assumed that the trend of increasing the river discharge of the river will remain in the following years. Accordingly, the risk of floods will also increase.

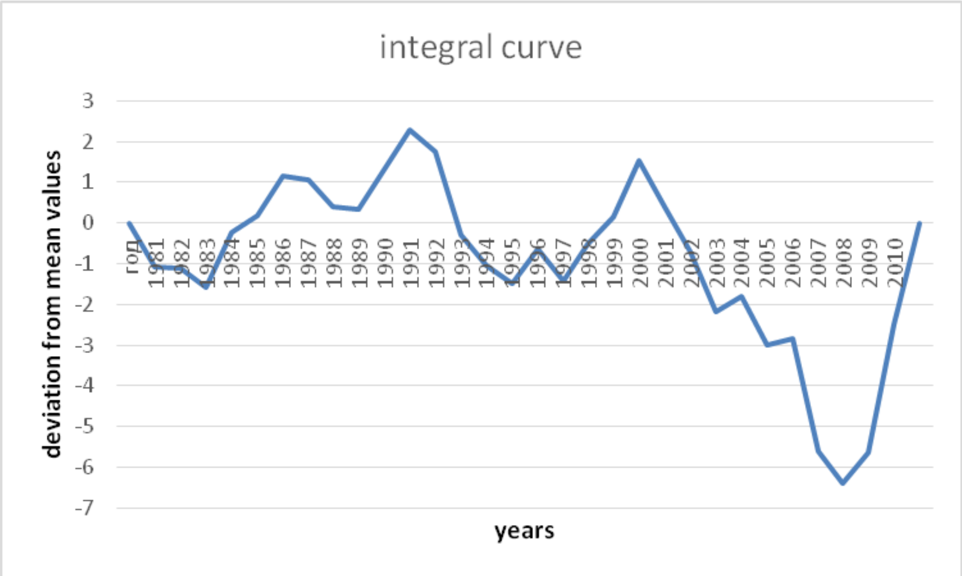

Figure 16. Deviation of the average annual discharge of the Sava River from the mean values over the observation period from 1981 to 2010

3.3. Correlation between flood forecasting and socio-economic impacts

In the course of further research, an attempt has been made to compare the simulated data of the average daily water discharge in rivers per month and on peak days of the most severe floods in recent decades with the cost of material damage from floods. Unfortunately, such data is available only for the territory of Switzerland, therefore only three river basins located in this country were analyzed. Perhaps the comparison of hydrological and socio-economic indicators is still not fully scientifically sound, but this approach is promising in terms of enhancing the capabilities of the pan-European flood forecasting and prevention system. Thus, the next part of the scientific work is of an innovative nature and does not pretend to high accuracy of calculations.

With the help of the data of the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, the dates and geographical location of the most devastating hydrological phenomena in the last decades were revealed. Since the scale of floods, mudflows and landslides is shown only in the graphic version on the map. It is estimated at the approximate cost of the damage. It was decided to translate this data into an average digital equivalent (see the results in the Table 4) to further identifying the correlation with the simulated water discharge rates of the rivers according to the site of the "HYPE" system. The periods with the greatest amount of destruction in the three studied river basins located in the Swiss Alps were chosen.

On 24 and 25 August of 1987, roughly one month after the devastating events in Graubünden and Ticino, especially the Alpine region was badly affected. Erosion along the Reuss River caused the bursting of dams and the undercutting of roads. Large areas in the lower flatland of the Reuss remained inundated. Debris flows caused high damage e.g. in the village Münster in the canton Valais. In the canton Ticino especially traffic infrastructure was affected (Zeller et al. 1988).

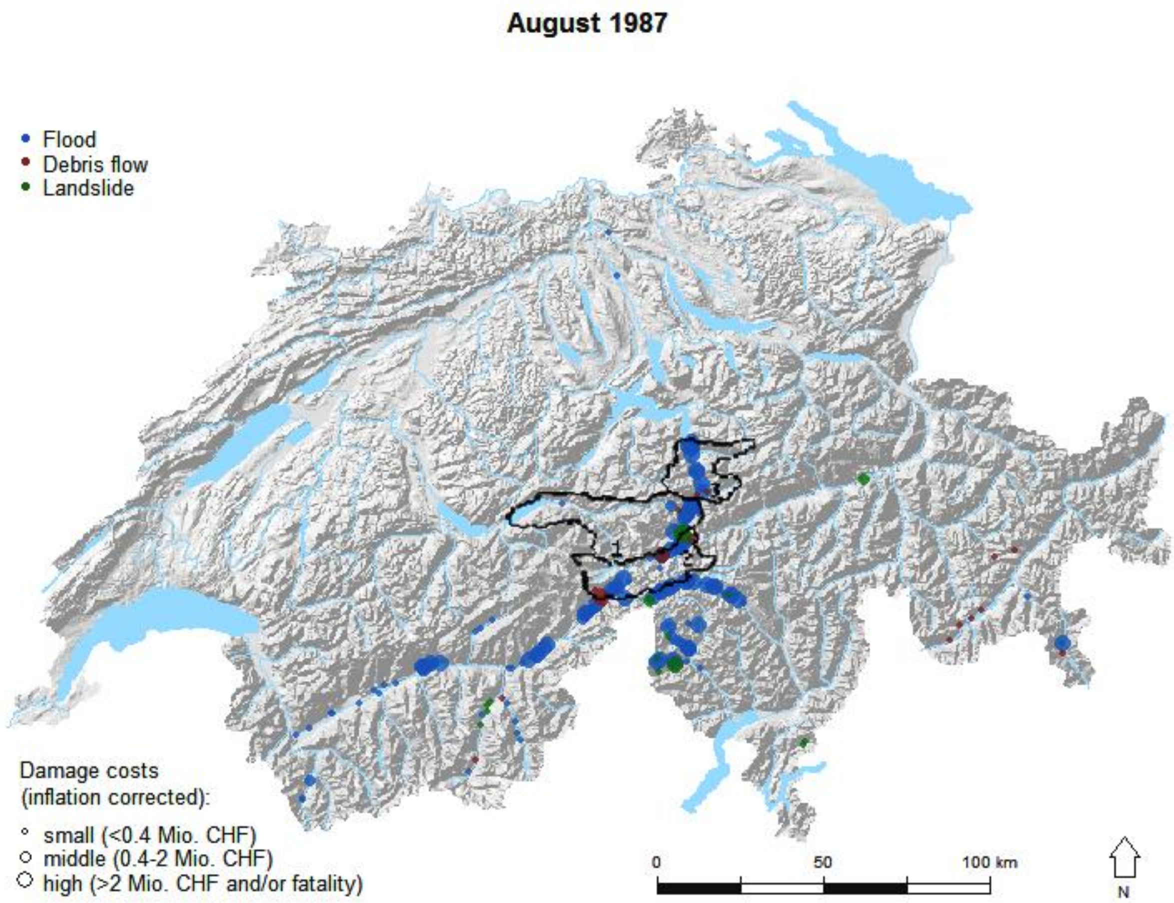

Figure 17. Flood and landslide damage events in August 1987

Long lasting rainfall over the cantons of Valais and Ticino caused floods on the 24 September of 1993 (Figure 16 in appendix). In Brig, bed load clogged a bridge over the Saltina River, whereupon parts of the town with a lot of buildings were covered with material several meters high. Two persons died in Brig during this flood event (Röthlisberger, 1994).

However, the studied ranges practically had no negative impact on these dates, except for the upper reaches of the Rhône River, where there were small disruptions because of flooding and landslides (Figure 17).

Extensive rainfall in May 1999 (Figure 17 in appendix) combine with snowmelt caused two consecutive flood events (11-15 and 20-22 May), which especially affected areas along lakes and large rivers in the Swiss Plateau), like e.g. Bern and Thun (both canton of Berne). Flooding occurred in almost all large lakes of Switzerland situated north of the Alps, and the rivers exiting the lakes were proportionally more effected (Hegg et al. 2000).

At this time, devastating floods affected the basin in the headwaters of the Melhaa River, while the other two basins southward practically did not suffer (Figure 17 in appendix).

The southern side of the Alps was affected by the long lasting rainfall of 13-15 October 2000 especially (Figure 18 in appendix). The extreme high water-level of Lago Maggiore in the canton of Ticino caused substantial damage especially in the city of Locarno. Erosion, landslides and debris flows caused very large damage in the entire canton Valais. During this event, 16 persons lost their lives, 13 thereof in the village Gondo in the canton of Valais (Hegg et al. 2001).

Again, only the Rhone River basin suffered from three territories, despite the fact that the basins in question are directly adjacent to each other and differ only in the general direction of the valley and in the exposures of the slopes (Figure 18 in appendix).

The flood event of 21-22 August 2005 was the most costly event since the beginning of the systematic data collection in 1972 (Figure 19 in appendix). Damage was caused along the large rivers in the Swiss Plateau, in the Prealps and in central Switzerland. The heavy rainfall that caused six fatalities and led to large-scale inundations, debris flows, landslides, hillslope debris flows (Hilker et al. 2007) (Figure 20 in appendix). Long lasting rainfall caused the exceedance of the capacity of the Jura lakes and the river Aare on 8 and 9 August 2007. Overflowing streams severely damaged villages in the cantons Aargau, Solothurn, Basel-Landschaft, Bern and Vaud (Hilker et al. 2008) (Figure 20 in appendix). However, in the studied areas, the floods were not so serious, and the valley of the river Rhone was not affected at all.

As can be clearly seen from the maps and the resulting summary table (Table 5), major floods that cause significant damage can bypass not only the parts of the mountain system that are remote from each other, but even neighboring river basins. In such cases, the spatial errors in the forecast of precipitation, even at 20 kilometers, can be of decisive importance.

Table 4. Approximate total damage costs (Mio. CHF)

river basin	August 1987	September 1993	May 1999	October 2000	August 2005	August 2007
1. The upper reaches of the Aare River	10	0.2	2	0.8	20.6	0.6
2. Upper reaches of the River Ron	13.6	3.2	7.8	2	0.4	0.2
3. Upper reaches of the Melhaa river	9.4	0.2	0.2	0.2	13.8	0.8

In the process of comparison between the magnitude of the material damage caused by floods, mudflows, landslides and simulated water discharge in the rivers of the basin, ambiguous results were obtained.

For example, in the Aare river basin, there is a high relation between the damage caused with a simulated forecast of river water discharge on flood days, and almost no connection with the average forecast for the whole month. This situation is quite understandable, since the individual days of peak water consumption do not mean a permanent excess within a month.

However, in the Rhone River basin, the situation is quite opposite: there is a clear connection with the average daily values for the month and there is absolutely no correlation with the forecast for the days of floods (Figure 21 in appendix). There may be several reasons for this: insufficient calibration of the prediction model for a given basin, successful protective measures that prevented large damage in case of a significant flood, or too strong averaging of the indicators. Probably, the calculation of the forecast is given for the basin as a whole (water discharge along the main river at the hydrological station at the base of the basin), while floods and mudflows occur alternately, in different parts and on different slopes of mountain ridges, negligibly affecting the overall indicators for the basin. That is why the average monthly data are more indicative than for specific dates.

In the upper reaches of the Melkaa River, direct medium-level dependence is again observed with simulated data for the days of floods and there is no strong connection on the average for the month (Figure 22 in appendix).

Therefore, despite some degree of uncertainty, it should be noted that the model mostly works correctly, on the dates designated by the Swiss Federal Research Institute as days of destructive floods that the model always showed without exception the significant excess of water discharge in the river over the mean values.

Table 5. Comparison the simulated river discharge and total damage costs in the upper reaches of the Aare River

dates	Modeled average daily water discharge in a given month (m3/s)	Modeled average daily water discharge in peak flood days (m3/s)	Approximate total damage costs (Mio. CHF)
August 1987 (peak 24,25)	6.7	22.7	10
September 1993 (peak 24)	9.76	19.3	0.2
May 1999 (peak 11-15, 20-22)	27.9	27.1	2
October 2000 (peak 13-15)	10.77	30.79	0.8
August 2005 (peak 21-22)	15.65	54.14	20.6
August 2007 (peak 8,9)	8.7	22.51	0.6

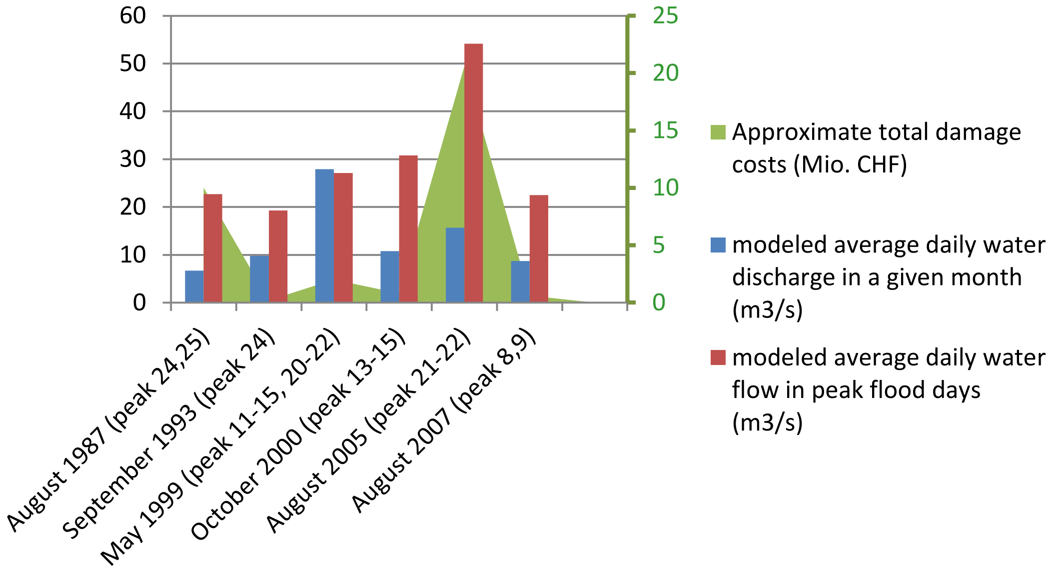

Figure 18. Comparison the simulated river discharge and total damage costs in the upper reaches of the Aare River

3.4. Comparison of the forecast scenarios

As a result of the comparison of the forecast scenarios for the main hydrometeorological parameters, the following conclusions were made:

- How much faster and higher will the global temperature rise because of an increase in the carbon dioxide content in the atmosphere, so faster threats of dangerous hydrometeorological phenomena, especially in the wetter parts of the highlands, will increase (Figures 23, 24, 25 in appendix).

-According to scenarios predicting the stabilization of carbon dioxide and temperature during the coming century, it is possible to gradually returning some hydrometeorological parameters (for example, average water discharge in rivers) to the initial indicators.

-The increase in the contrast of hydrometeorological phenomena is forecasted, both in their spatial location and in temporal scale (intensity intensification).

- The most likely scenarios (averaged forecasts) are moderately unfavorable for the socio-economic development of countries and for natural ecosystems, which requires compulsory costs for the development and improvement of forecast methods and protection against adverse hydrological phenomena in mountain areas (Table 1 in appendix).

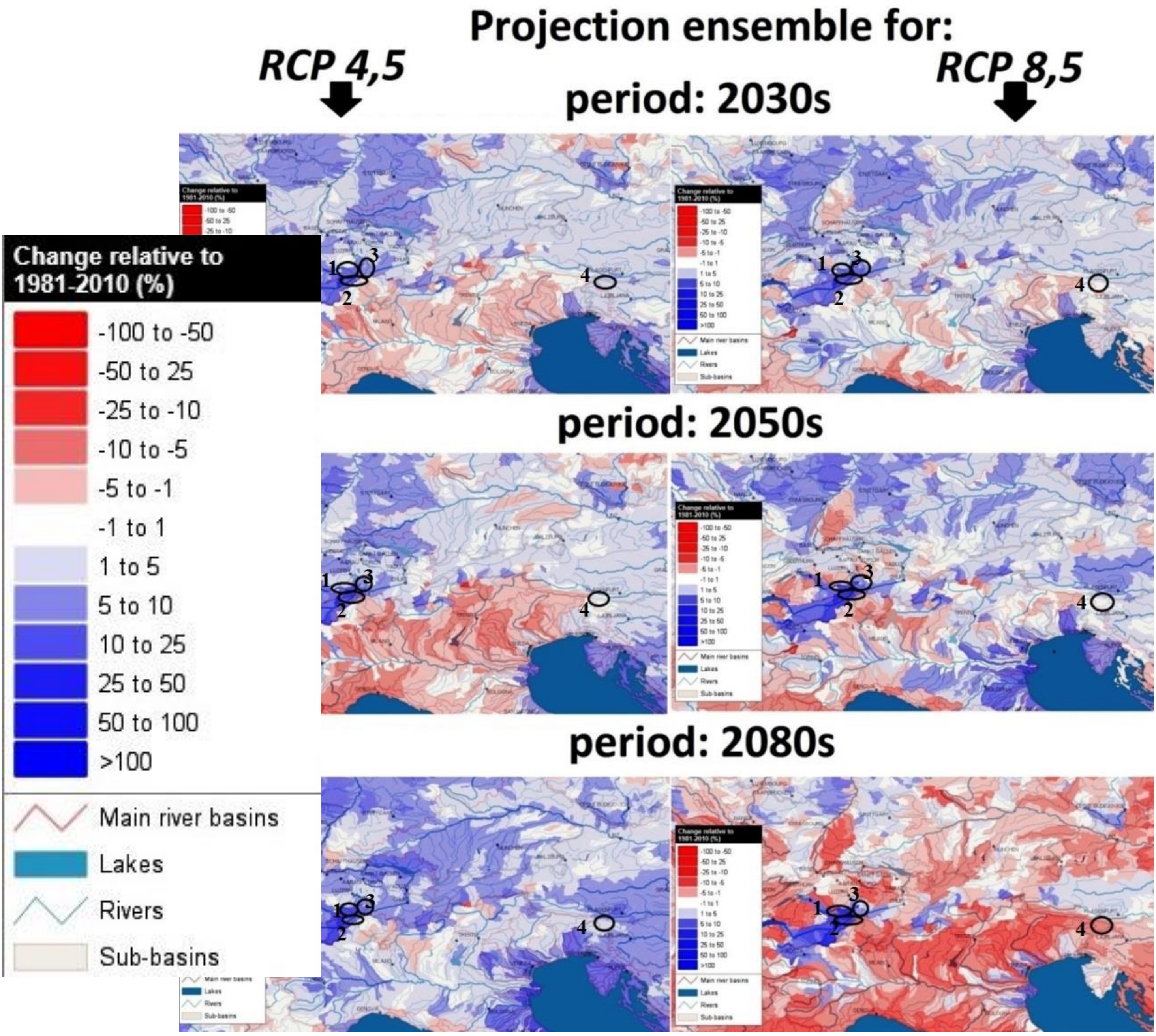

Figure 19. The simulated change in the amount of river discharge according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s. Signed numbers: 1. The upper reaches of the Aare River above Interlaken (Switzerland) 2. Upper reaches of the River Ron (Switzerland) 3. Upper reaches of the Melhaa River (Switzerland) 4. Upper reaches of the River Sava Bojinka (Slovenia)

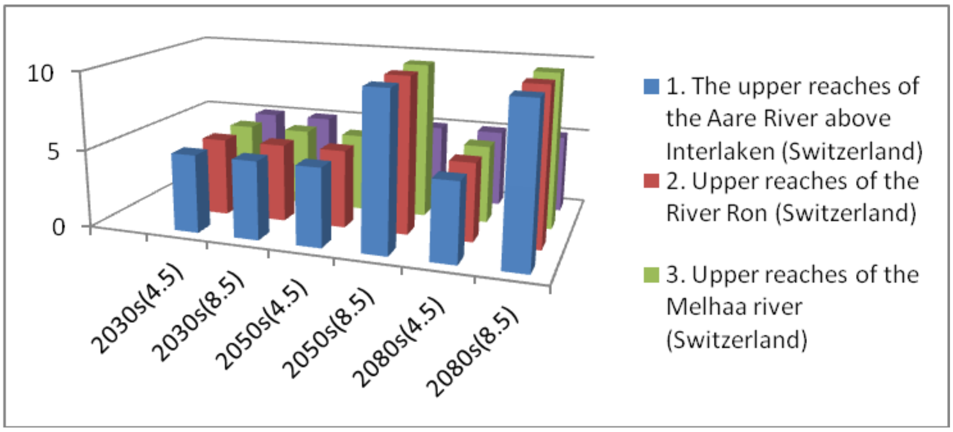

Figure 20. The simulated change for precipitation according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s

3.5. Climate change impacts on mountain floods

In the context of current and future climate change, flood risks in mountainous areas are increasing due to overall Alpine temperature increases. Large floods in mountain basins are likely to become more frequent with climate change. Analysis of climate change scenarios indicates that snowmelt periods will begin earlier in the spring for Alpine regions, leading to a shift of hydrological regimes and maximum monthly discharges. Climate change has also been proven to result in complex non-linear changes in temperature gradients; in the European Alps, minimum and mean maximum temperatures have shown variable increases (in some cases have remained constant) depending on the altitude range considered. Such changes in temperature gradients highly affect flood runoff. Furthermore, variations in cloudiness and atmospheric transmission are altering quantities of incoming solar radiation. Snowmelt models, which commonly link temperature to incoming radiation to produce the equivalent precipitation component of hydrological models, are impacted as a result. Moreover, the resulting changes in radiation are not aligned with changes in air temperature caused by climate change indicating that snowmelt models calibrated in the past must be scrutinized in order to ensure that they still provide valid melt calibrations in today's models (Gray and Male (Eds.), 1981).

Because a number of factors influences flood events, it is difficult to confidently state that, extreme flood events in Queensland will increase in intensity or frequency as a result of climate change. However, increased chance of flash flooding because of an increase in short-term heavy rainfall events both seem highly likely, based on current assessments of projected climate change.

Average rainfalls in South-East Queensland are projected to increase in summer and decrease in winter. Regarding short-period (e.g. less than 24-hour) rainfall events, the Intergovernmental Panel on Climate Change recently concluded that it was likely such heavy precipitation events would become more frequent over most land areas. This could lead to increased flood risk, especially for flash floods. A re-evaluation of probable maximum precipitation could be required, along with flood resilience capacity for critical infrastructure such as dams and bridges.

Despite significant uncertainties in projections for future climate change, for the regions studied, most scenarios provide for a small average annual reduction in precipitation, but a more uneven distribution over the seasons. An increase in the contrast of climatic conditions for both regions is forecasted. This means that atmospheric precipitation will fall less often, but with greater intensity, which will increase the risk of dangerous hydrological phenomena.

4. Discusions

4.1. Recommendations for reducing flood damage

To increase the accuracy of forecasts, it will also be necessary to develop new techniques and computer models using artificial intelligence and constant high-precision satellite monitoring in various ranges.

However, accurate flood forecasting is in the near future, it is impossible to completely avoid damage simply by warning about dangerous phenomena.

It is necessary to build a significant number of new hydraulic structures - dams, dams, water protection shafts, floodwater reservoirs, etc. It is also possible to increase artificially the capacity of the channels by expanding, deepening, straightening the flow at key points, and constructing additional irrigation channels.

In some cases, it is possible to reduce the amount and intensity of local precipitation by correcting the landscape, relief, and temporary changes in the physical parameters of the lower layers of the atmosphere.

Recently, the direction of large-scale landscape engineering has become popular. In the Soviet Union created huge reservoirs and planned to turn rivers, so now projects are being developed to create artificial mountains and other large elements of the landscape (in Germany and the Arab Emirates). Similar projects can be successfully applied to flood protection, although for limited territories.

Naturally, such manipulations should be carried out only in view of the absence of harmful consequences for the ecosystem and under the control of environmental organizations. Since catastrophic floods can cause serious damage not only to humans but to natural biodiversity and natural landscapes disruption as well. Sometimes deliberate modification of landscape properties will cause less harm to nature than potential dangerous hydrological phenomena, such changes may be justified.

Therefore, in order to change the spatial distribution of the amount of precipitation, it is necessary to understand the basic mechanisms of cumulonimbus clouds. In a territory with a complex terrain and a diverse underlying surface, rain clouds will develop most over the rising air currents and in the presence of a large number of condensation nuclei in the atmosphere. Usually, the degree of development of the cloud determines the further intensity of precipitation. Rising air currents can arise above mechanical obstacles (hill, mountains, slope, and high buildings) and over a territory having a higher temperature than the surrounding or neighboring territory. In sunny weather, warmer and provoking ascending currents are rocks, dark underlying surface, possibly high grass, urban settlements.

In cloudy weather and at night, warm streams appear above water bodies, forests, and cities. That is why in almost every megalopolis of the world meteorologists record an increase in the intensity of precipitation and their quantity in the warm season - constant thermal ascending flows in combination with a mechanical rise when air is overcome by high-rise urban buildings and the growing content of aerosols over the city when fuel (condensation core) is burned. If we need to achieve the opposite effect, in the case of cities, emphasis should be placed on the light surfaces of buildings and roads to reduce heating due to solar radiation increase the number of green spaces and water bodies to a maximum, abandon internal combustion engines and industrial facilities within the city. Such measures can reduce the risk of intense precipitation and, therefore, urban flooding.

In the case of natural objects, everything is a bit more complicated, but the same mechanism of cloud development works. Primary, you need to choose an area where heavy precipitation is undesirable, but they do happen. Suppose this is a narrow mountain valley, which is an important transport artery. Let us try to find out what causes intensive precipitation here. Perhaps, the influence of neighboring relief elements is affected - the dark surface of the hill on the windward side, over which clouds are intensively forming, and then they are carried here, or clouds grow over the nearest city, and then, cooling down, fall over the valley. If the reason for the intensification of precipitation is outside, we can try to eliminate or neutralize the cause.

The positive roughness of the relief can be equalized or at least increased the albedo in order to reduce the surface heating, for example, plant the surface with wood if it was previously bare or if it is impossible to lighten the surface with available methods. By increasing the albedo, we reduce the probability of local intense precipitation in the daytime, but if heavy rains occur at nighttime, it should be another reason. If such a reason is a forest or a reservoir, then most probably nothing we can change (we will not cut down the forest or drain the lake). However, we can try to create an interception of precipitation by building an additional physical barrier between the cause of convection and the valley being studied, for example the wall or an artificial mountain. Instead of such an obstacle, one can simply create descending air currents that will precipitate clouds before they enter the valley.

Descending currents create a cold surface - a pond, a reservoir on a cold mountain river or a rapidly cooled surface of a rocky wasteland, sometimes even just a negative form of the relief. If the rocky surface at night will be cold and will be able to provoke the descending air currents, then in the daytime due to solar radiation it will act exactly the opposite, and this may entail increased daytime intense precipitation in the study area.

If there are no external reasons for increasing precipitation in the valley, then it is probably the cause of the provocation of clouds precipitation during the mechanical upsurge of air masses. In this case, we act, as well as with external causes. We check whether there are any sources of condensation, nuclei that can be eliminated (fires, industrial pipes).

To reduce the rains during the daytime, the slopes albedo can be increase, especially the windward one, by changing the color of the underlying surface. It reduces the heating of the valley by creating a chain of reservoirs, if possible. As seen it is a rather complex and situational process, depending on the specific place, the surrounding territories, the season of the year and the time of day. It is necessary to take into account the entire landscape in a complex manner both within the studied territory and beyond, then it is possible to achieve a significant decrease in the intensity of atmospheric precipitation, and hence, reduce the risk of flooding. This method allow to redistribute precipitation on the terrain. It can protect only some of the most important areas but will not change the weather in the whole region.

It is interesting that it is the reduction of precipitation that is the most difficult by changing the parameters of the landscape and mesorelief, it is much easier to provoke precipitation or change the air temperature and temperature fluctuations, wind, humidity. These opportunities will be useful in combating another dangerous hydrological phenomenon - drought, in the arid regions of the planet and can become objects of new research. In addition, the possibility of such adjustment of the microclimate of individual territories can play a key role in the organization of new recreational zones with a more favorable microclimate for recreation than in the surrounding area.

4.2. Discussions of the differences in the prognosis in different scenarios

Continuing to develop the idea of increasing contrast, the changes in total river runoff in the studied basins were analyzed (Table 3 in appendix). In models of river flow changes, the contrast is even brighter. We see an increase in river runoff in the highlands of the Swiss Alps from 5-10% in the 2030s to 50% in the 2080s according to scenario 4.5. When using the maximum scenario (8.5), we observe a more dramatic increase in river runoff from 10 to more than 50% in the same period. At the same time, the river runoff in the highlands of the Julian Alps (Slovenia) increases insignificantly under scenario 4.5 and practically does not change under scenario 8.5 (Figure 25 in appendix). This situation can be explained by a regular increase in evaporation as a result of a rising in the average temperature and the possible depletion of snow and glacial reserves in the upper reaches of the rivers. If analyzing not only the selected areas, but also the map as a whole, we can see that according to the scenario 4.5 to 2080m, not only the volume of carbon dioxide emissions and global temperature stabilizes, but also the volume of the average annual river flow in the Alps will begin to approach modern indicators.

Analysis of changes in the water equivalent of snow in the future in two scenarios shows a primary increase in indicators, and then a rapid decrease. The difference between scenarios is only in the rate of change in indicators. Only for the relatively drier Julian Alps, the initial and constant decrease in the water equivalent of snow is predicted according to both scenarios from 1-5% in 2030s to 10-25% in the 2080s. The water equivalent of snow in the studied basins on the territory of Switzerland will increase relatively to the modern by 5-10% in the 2030s considering both scenarios. However, according to the soft scenario (4.5), the water equivalent of snow will remain above the present and in the 2050s, and only in the 2080s, it will decrease by 10-25% from the current one. At the same time, the maximum scenario describes a reduction of 10-25% both in the 2050s and in the 2080s (Figure 24 in appendix). The above-described changes are easily explained by taking into account the simultaneous increase in temperature and the amount of precipitation. Snow accumulation will initially increase, but as the temperature rises, the snow line will gradually shift higher along the slopes until it disappears into a seasonal snow line, simultaneously with intensive melting of mountain glaciers.

Comparing the total prognostic charts of the total runoff from the surface, a clear correlation is observed with both the amount of precipitation and the volume of river discharge. For the three river basins studied in the Swiss Alps, the forecast for all periods for both scenarios is 10-25% of the initial increase. In addition, an increase in all periods and scenarios of 1-5% is projected for the fourth site in Slovenia. The exception is the 2080s under scenario 8.5 where the Swiss Alps show an increase in runoff of up to 50% and in the Julian Alps match current indicators (Figure 25 in appendix).

4.3. Optimization of water resources management for flood forecasting

There is the strong tendency for widespread flooding to occur during La Niña events, the 'wetter' extreme of the El Niño - Southern Oscillation, ENSO. If La Niña events, or their effects on Queensland rainfall, became more frequent or more intense because of global warming, we can expect more frequent flooding. Currently it is projected that, in the future, ENSO variations may be different from those in the recent past. However, we are not currently able to project confidently what those changes will be.

To optimize water resources management for flood forecasting and hydropower operation purposes, it is crucial to have accurate estimates of meteorological forcings in space and time, particularly in Alpine terrain. However, within complex topography the characteristic spatial scales of hydrological forcing is captured as a typically and poorly even with a relatively dense network of measurements (Wratt et al., 1996). Moreover, topography affects rainfall and snowfall patterns through the so-called orographic and shadowing effects. Due to orographic effects and weather patterns, there is on-going research as to whether precipitation, in general, increases with elevation. For instance, precipitation accumulation trends can show considerable scatter with altitude depending on the region’s exposure to wind and synoptic situations (Sevruk, 1997).

Furthermore, depending upon the predominant wind direction, rain shadows can be created when more precipitation is deposited at or near the crest and much less, precipitation is deposited at lower elevations (Sinclair et al., 1997). In the particular case of the European Alps, an analysis of long-term rainfall records demonstrated that maximum precipitation rates are observed on both the upper southern and northern faces (Frei and Schär, 1998). Regression analyses of corrected annual precipitation versus altitude in the Swiss Alps have also shown that in the upper reaches of the Rhone River valley (i.e., the Valais), between 90 and 100% of precipitation variability is explained by altitude with greater precipitation rates found at higher elevations (Sevruk, 1997).

Furthermore, a climatological study (Attinger and Fallot, 2003) indicated that since 1975 over half of meteorological situations which have produced more than 100 mm/day of precipitation over three days in the upper Valais have originated in the south; these southerly events have deposited abundant precipitation on the upper windward and leeward sides of mountains. With southerly storms, precipitation in the Valais shows significant patterns on leeward sides where precipitation is effectively funneled into lower elevation areas due to shielding patterns created by adjacent high elevation mountains (e.g., the

Matterhorn at 4500 m) (Petrascheck and Hegg, 2002). In spite of a long-term knowledge on regional weather and precipitation accumulation patterns in the Swiss Alps, a non-exhaustive sampling of rainfall with few gauges located at high altitudes is unable to effectively capture short-term, catchment-scale, orographic effects during flood events (when the steep slopes and relatively shallow groundwater depths typical of Alpine areas generate short response times) (Petrascheck, 1996).

A sparse rain gauge network at upper elevations necessitates a proper quantification of the local precipitation-elevation relationship using an extended description of topography (Frei and Schär, 1998). Moreover, the inability of correctly reproducing areal rainfall leads to notable failures of the ensuing models of the hydrologic response, which are sensitive to input volumes at the catchment scale (Nicótina et al., 2008). At reduced subcatchment scales, rainfall variability also has an important impact on peak flows (Mandapaka et al., 2009). Furthermore, a limited number of temperature stations in the region does not allow proper definitions of snow/rainfall partitioning during flood events. Accurate temperature fields are particularly important in mountainous regions because the combination of high temperatures producing snow/glacial melt or rain-on-snow processes can accelerate discharge production (Benestad and Haugen, 2007; Jasper et al., 2002; Sui and Koehler, 2001).

In the future Australia's population continue to grow, placing increased pressures on our waterways, many of which already experience high levels of flood risk. A growing population will result in increased development on the floodplain and the temptation to build in flood corridors. Rising land prices and a resulting move to smaller block sizes are expected to result in cities becoming more densely populated, increasing the chance of flooding in the cities. More houses built closer together increases the number of houses potentially exposed to flood damage.

5. Conclusions

Modern modeling methods are available but not well enough for prediction of sudden floods. Despite a certain relationship between the simulated data and the measured data, the underreporting of peak values is too large, and therefore significant improvements are required.

A more complex orography of the Alpine region than Australia, despite the high accuracy of weather forecasts throughout the year, complicates the distribution of precipitation on the slopes depending on the exposure. The greatest risks of flooding in valleys facing west or having a high eastern slope, contributing to increased condensation. However, the lee of the eastern and shady northern slopes often accumulate a huge amount of snow in the winter, which may begin to melt with warming and provoke a significant rise in the water level in the rivers even with small liquid precipitation that stimulate snowmelt. At the same time, the southern and western slopes are warmer and contain less snow reserves, the absorbing capacity of the soil is higher and a much higher amount of precipitation is required for the beginning of the flood than for the northern and eastern slopes where the soil is often frozen and moisture moves along the surface without soaking. All these features should be taken into account in the calculation of flood peaks for the downstream rivers that take water from a number of upstream tributaries and hence have a mixed type of feeding.

In any case, both for Australia and for Europe, the primary task is to expand the network of automatic hydrometeorological stations, which will make it possible to inform more quickly and accurately about the risks of floods. The improvement of computer models will also increase the accuracy of hydrological forecasts in both regions. However, if the improvement of technologies and techniques for the Alps makes it possible to refine and advance the predictions for several days, for the tropical part of the Great Dividing Range, due to the peculiarities of the atmospheric circulation, the time gain will be no more than a few hours, which is still critical.

Methods for preventing dangerous hydrological phenomena and correction the microclimate of some territories

For better predictions of floods, in the first it is necessary to improve and refine existing methods. Better weather modeling and improved forecasting systems: the accuracy of weather modeling has improved substantially during the past decade. This improvement will continue as more accurate computer models are developed, and as these models are informed with better observational data. Real-time radar observation of rainfall and satellite monitoring of inundation will also improve (Bellerby et al., 2001).

As the science of weather modelling improves, more reliably prediction should be done to the near term - in the order of several days into the future - patterns and magnitudes of rainfall on our catchments. In the not-too-distant future, this should enable us to develop near real-time flood forecasting systems that link predictions of rainfall with the flow of water from our catchments and the resultant flood levels and velocities in our creeks and rivers and on our floodplains. These systems, which could potentially provide forecasts in near real time via the internet, will be able to provide flood forecasts with greater accuracy and longer lead times than today.

Better flood warning systems: The improved predictive systems described above will be increasingly linked to real-time flood warning systems. Such systems could realistically have several categories of alert that may significantly reduce damages associated with flooding by giving residents more time to prepare. Real-time flood models could be linked to interactive (internet based) maps that provide residents with detailed information on key issues such as:

- predicted peak flood levels, rates of rise for their location, and escape routes together with predictions of evacuation time and the provision of staggered 'get out' warnings to isolated residents;

- traffic network advice that assists with escape route planning to minimise congestion;

- the locations and availability of emergency centres and whether space is available.

These systems may have a simulation capability to allow disaster training and practices.

Better land use planning and floodplain management can mitigate the impacts of flooding.

Rapidly changing climatic conditions and the increasing risk of flooding undoubtedly require governments to develop scientific research in this field of knowledge and to apply urgent technical and economic measures to reduce damage from hazardous hydrological phenomena. That is why the author considers it necessary to continue studying the above-described problems at a more detailed level.

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26. http://www.dartmouth.edu/artsci/geog/floods/

27. http://www.worldclimate.com/

28. http://www.wri.org/watersheds/

29. http://www.floodsreview.vic.gov.au

Appendix

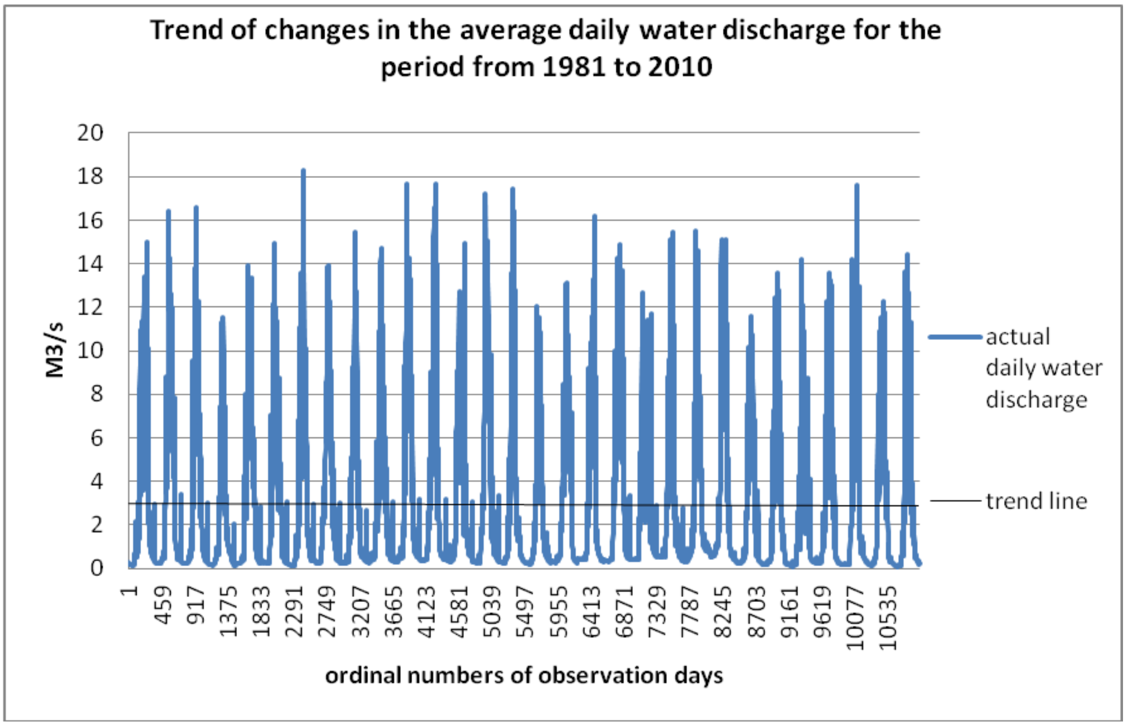

Figure 1 .Trend of changes in the average daily water discharge of Rhone River for the period from 1981 to 2010

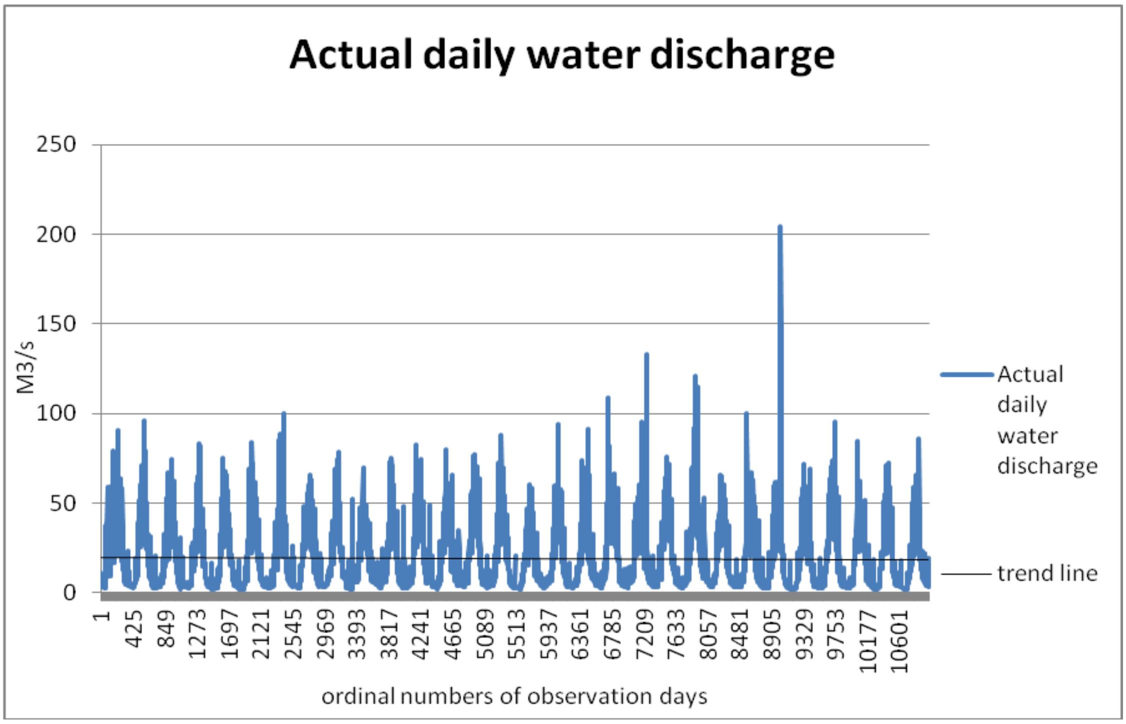

Figure 2.Trend of changes in the average daily water discharge of Aare River for the period from 1981 to 2010

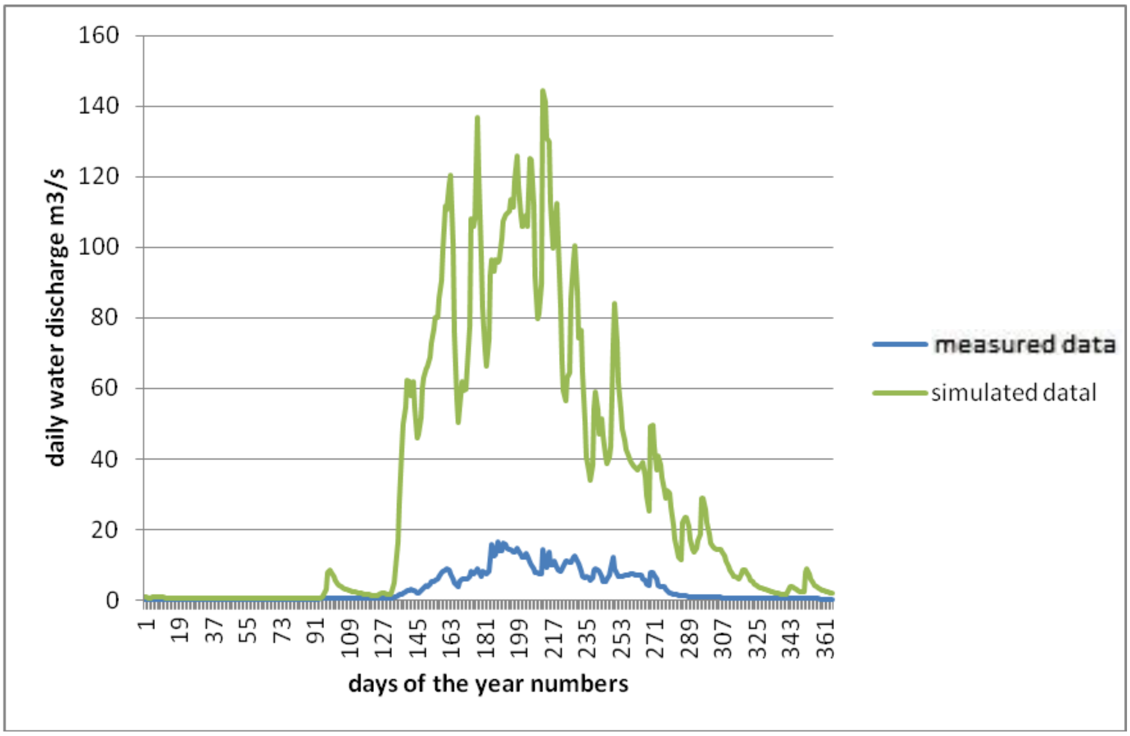

Figure 3. Daily water discharge graph in the upper reaches of the Rhone River. 1982 wet year (average water discharge 3.4 m3/s)

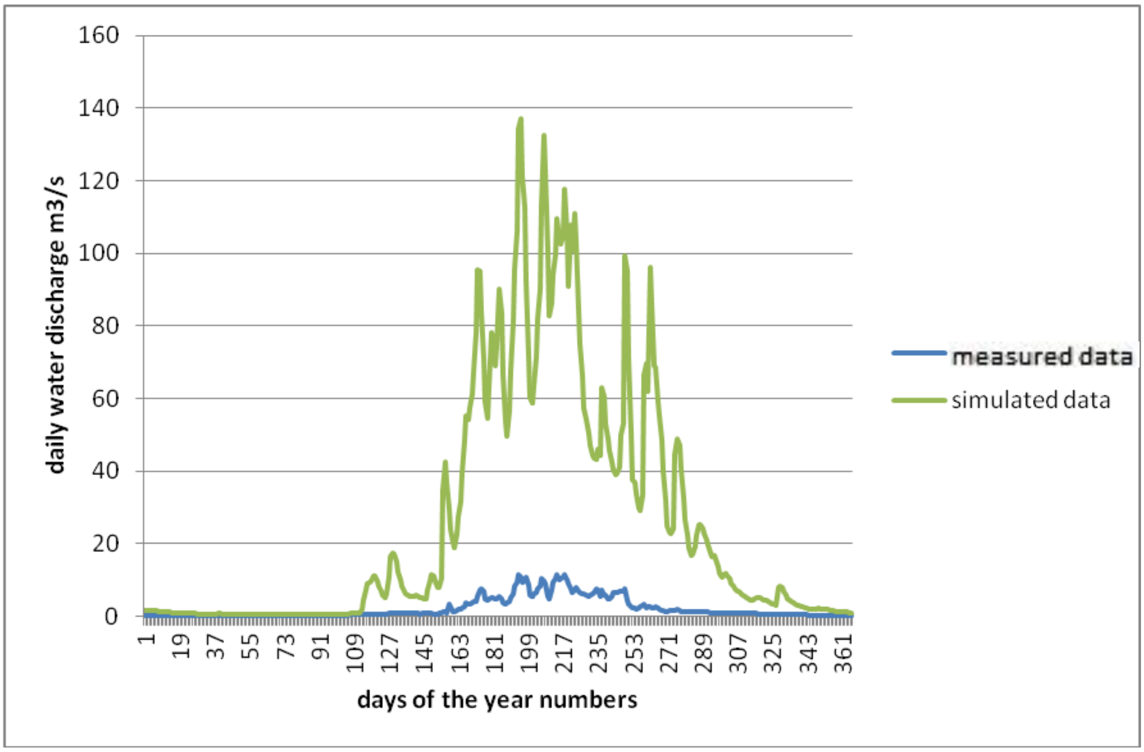

Figure 4. Daily water discharge graph in the upper reaches of the Rhone River. 1984 dry year (average water discharge 2.0 m3/s)

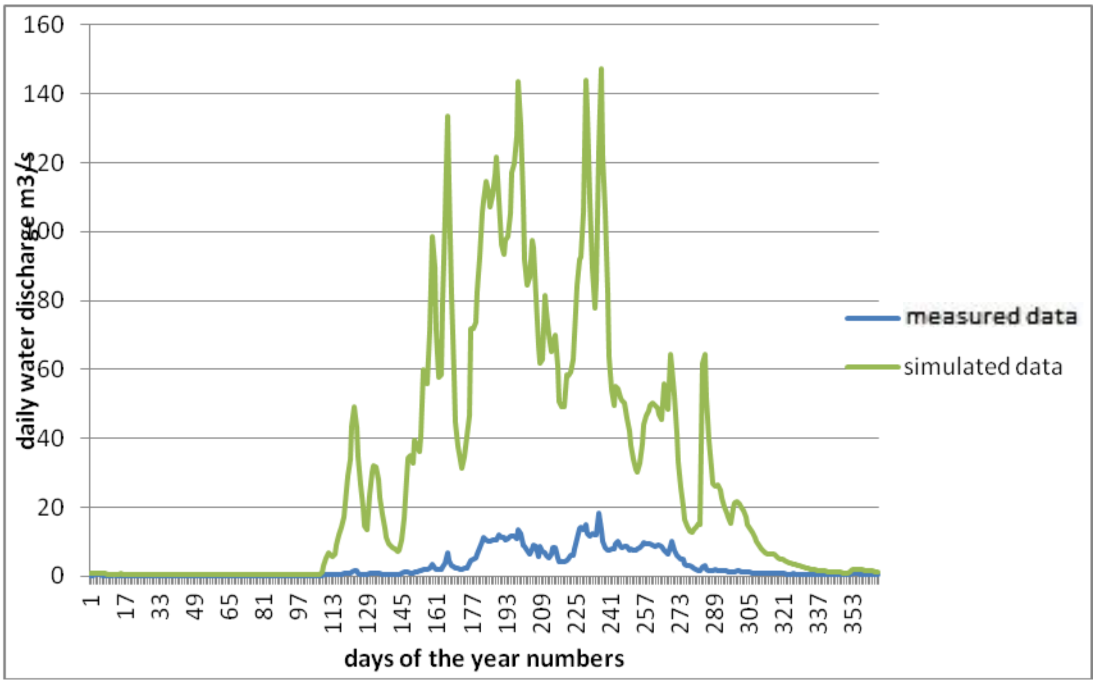

Figure 5. Daily water discharge graph in the upper reaches of the Rhone River.1987 medium wet year with high flood events (average water discharge 2.9 m3/s)

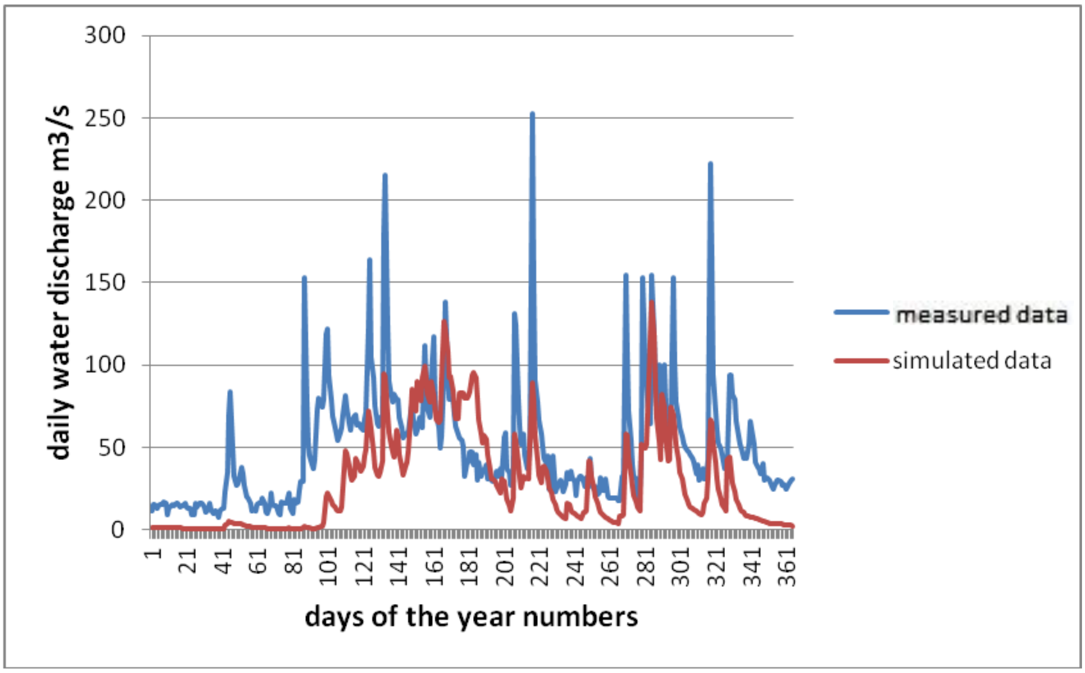

Figure 6. Daily water discharge graph in the upper reaches of the Sava River.1987 medium wet year (average water discharge 49 m3/s)

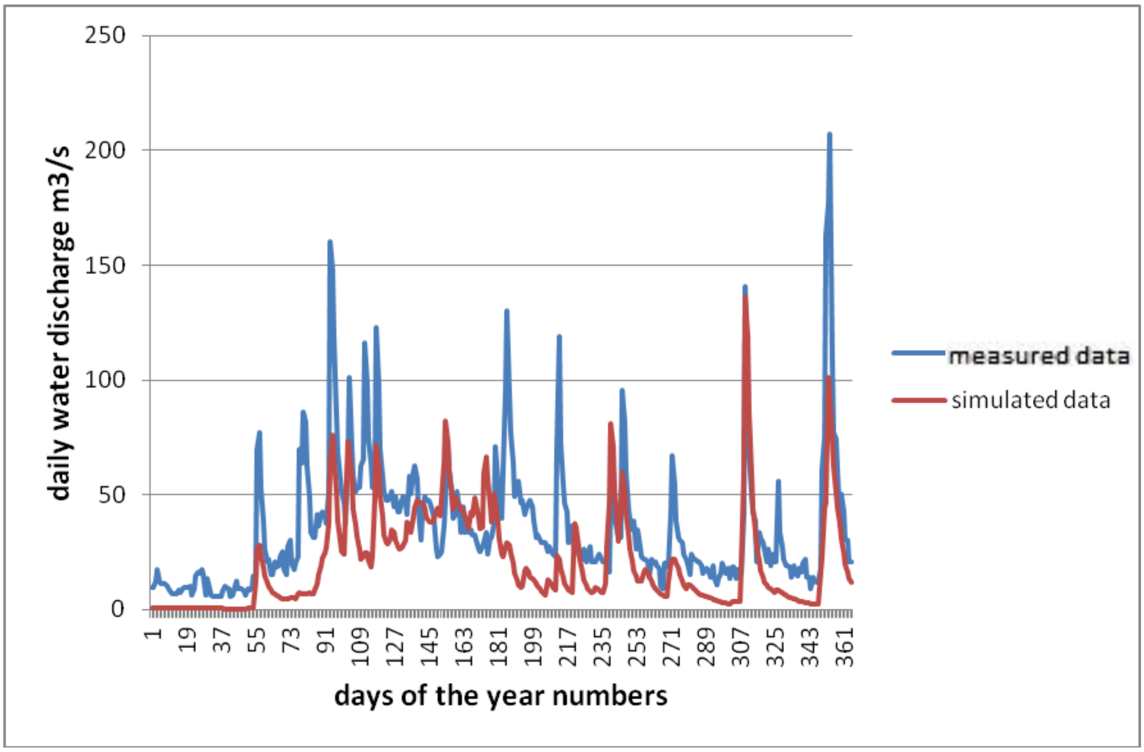

Figure 7. Daily water discharge graph in the upper reaches of the Sava River.1989 dry year (average water discharge 36 m3/s)

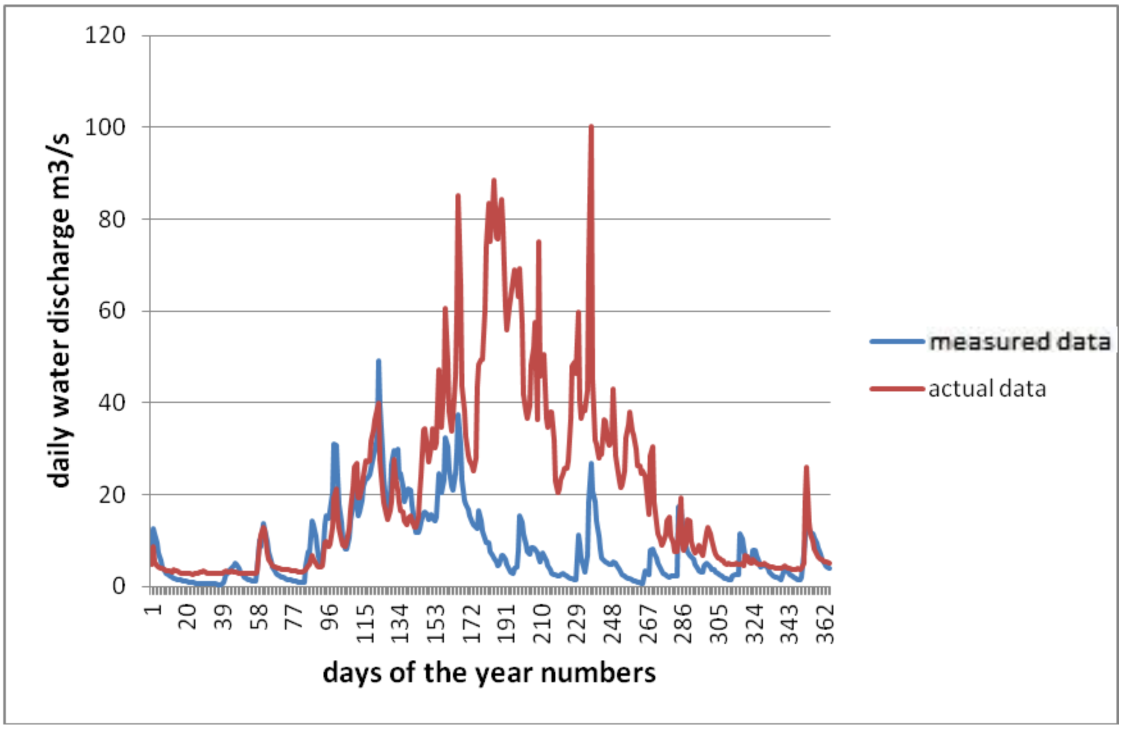

Figure 8. Daily water discharge graph in the upper reaches of the Aare River.1987

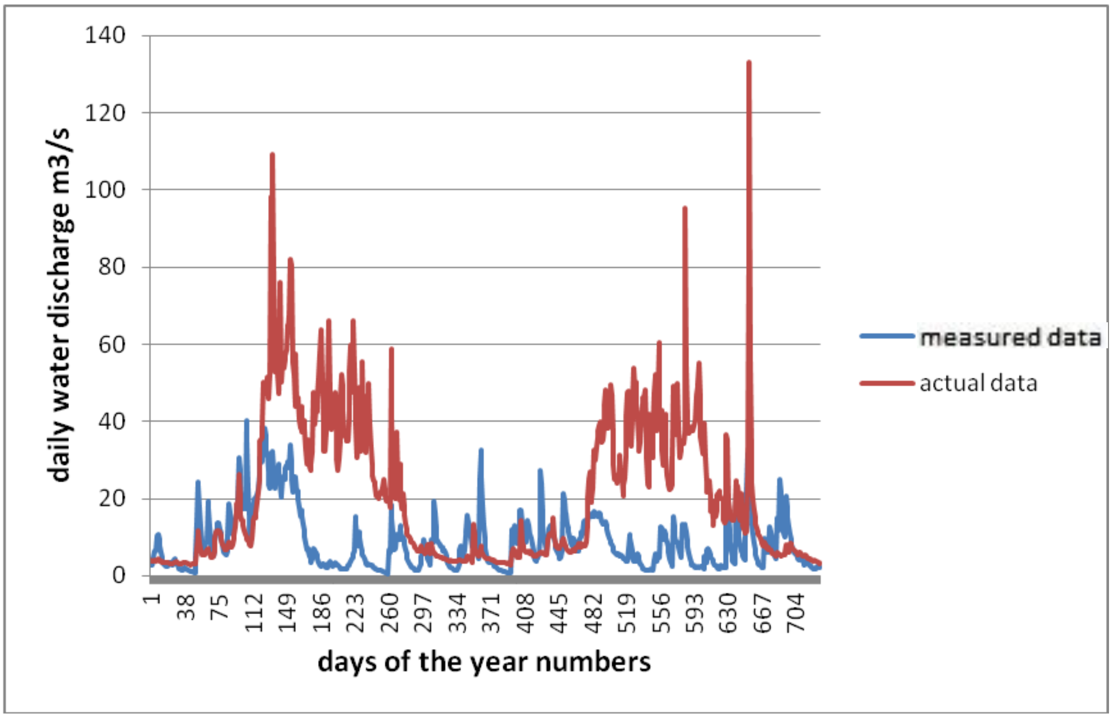

Figure 9. Daily water discharge graph in the upper reaches of the Aare River.1999

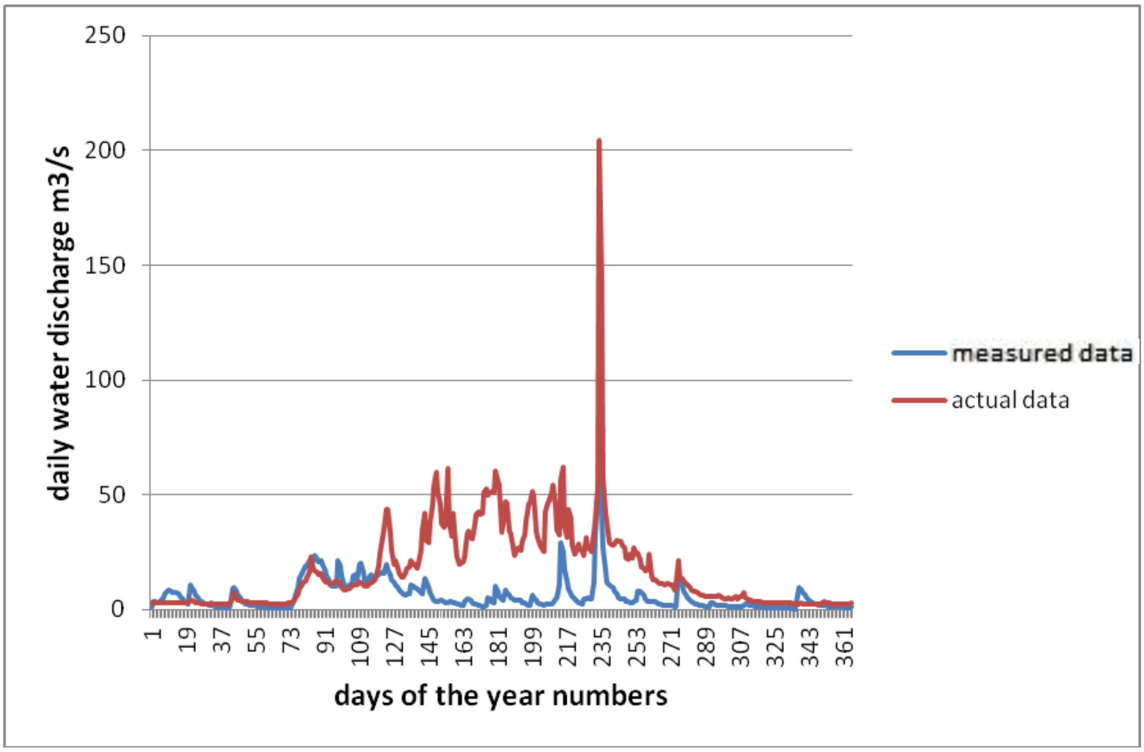

Figure 10. Daily water discharge graph in the upper reaches of the Aare River.2005

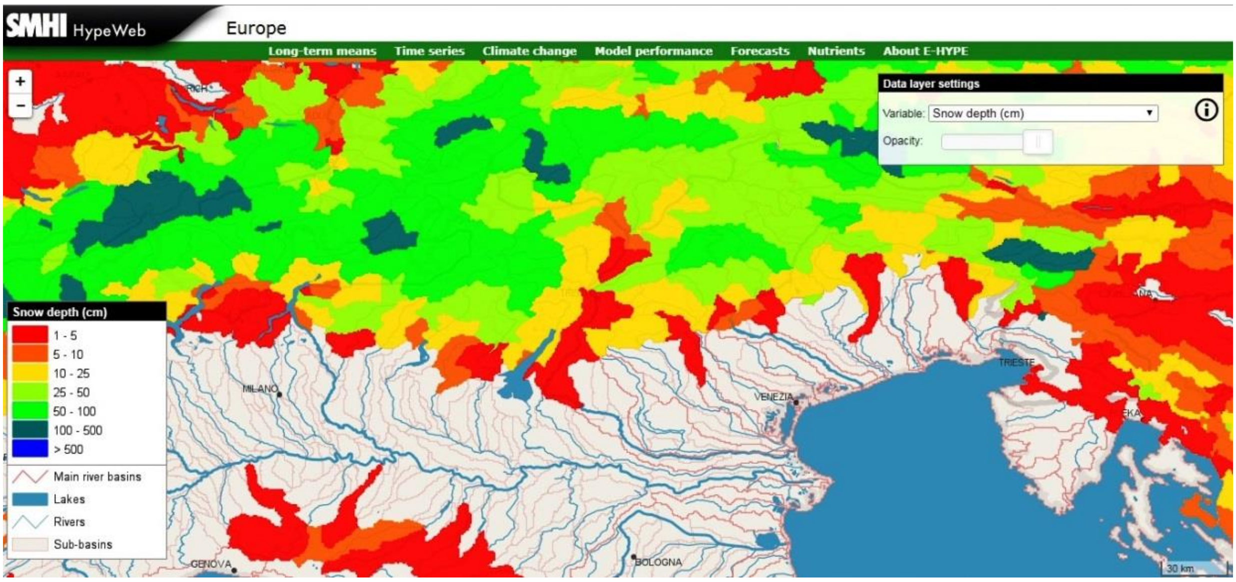

Figure 11. Average snow depth (cm) (data provided by hypeweb.smhi.se)

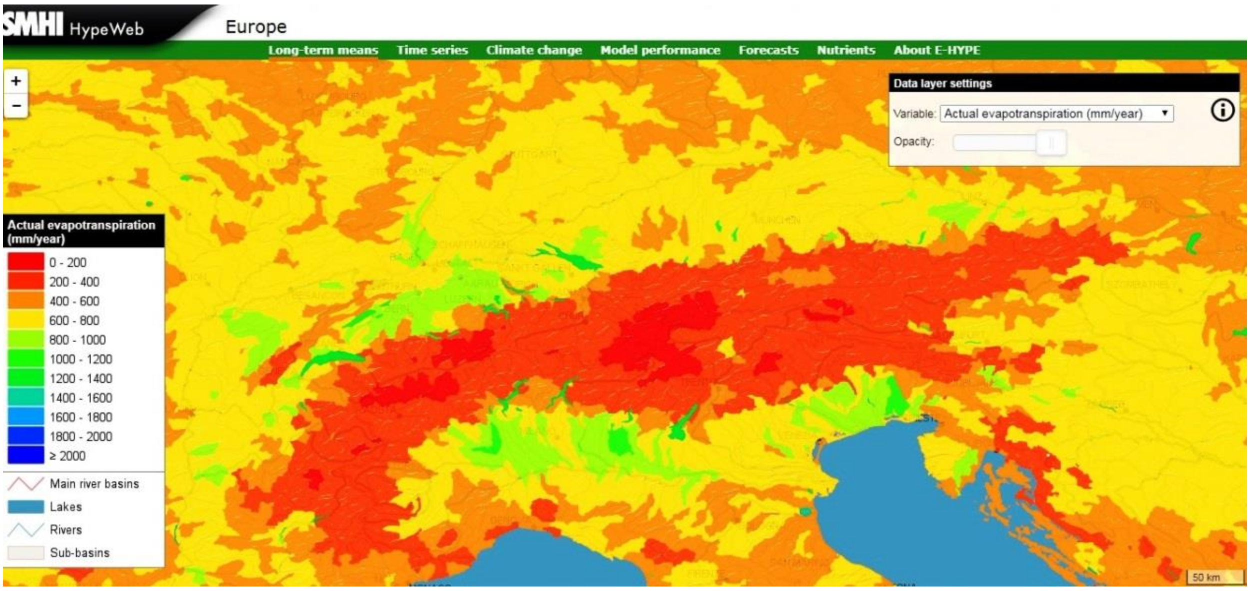

Figure 12. Average measured evapotranspiration (mm/year) (data provided by hypeweb.smhi.se)

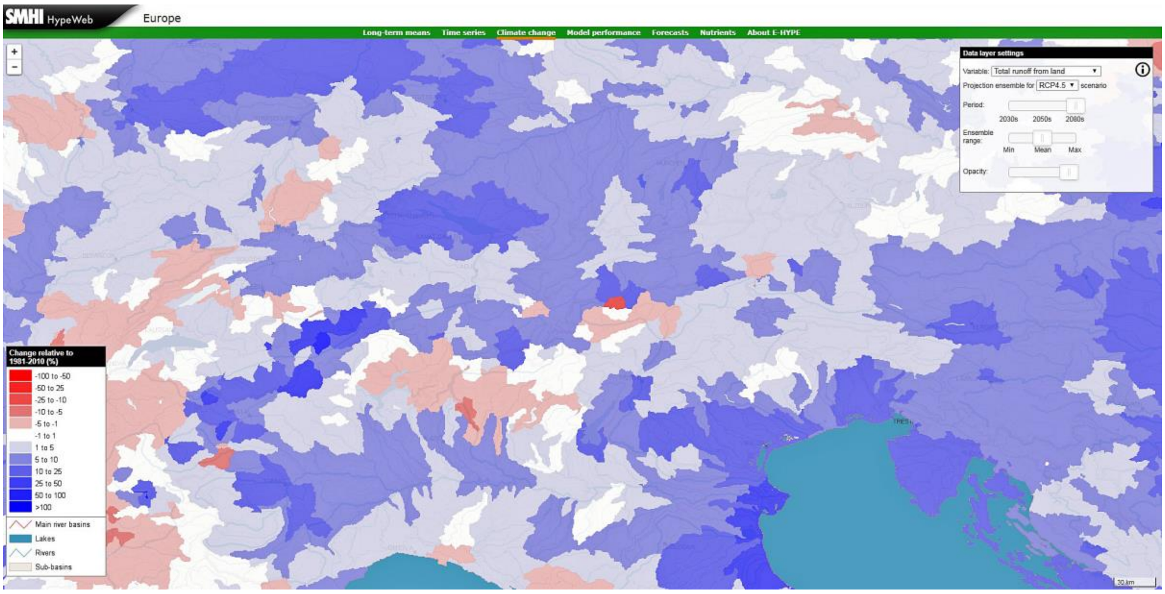

Figure 13. Forecast of the change in the total runoff from land. 2080s relative to 1981-2010(%) (data provided by hypeweb.smhi.se)

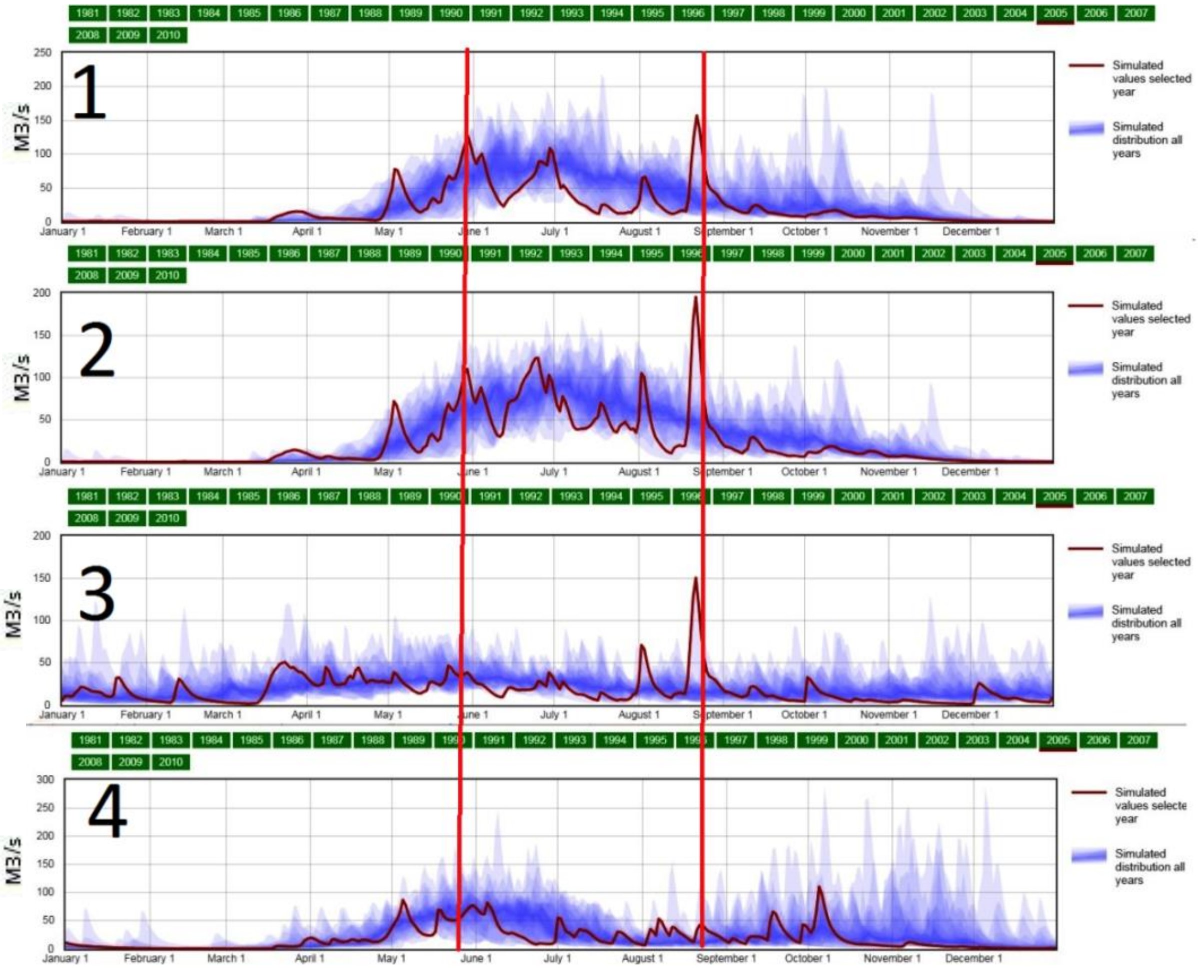

Figure 14. Comparison of water discharge peaks in the studied basins in 2005 (data provided by hypeweb.smhi.se)

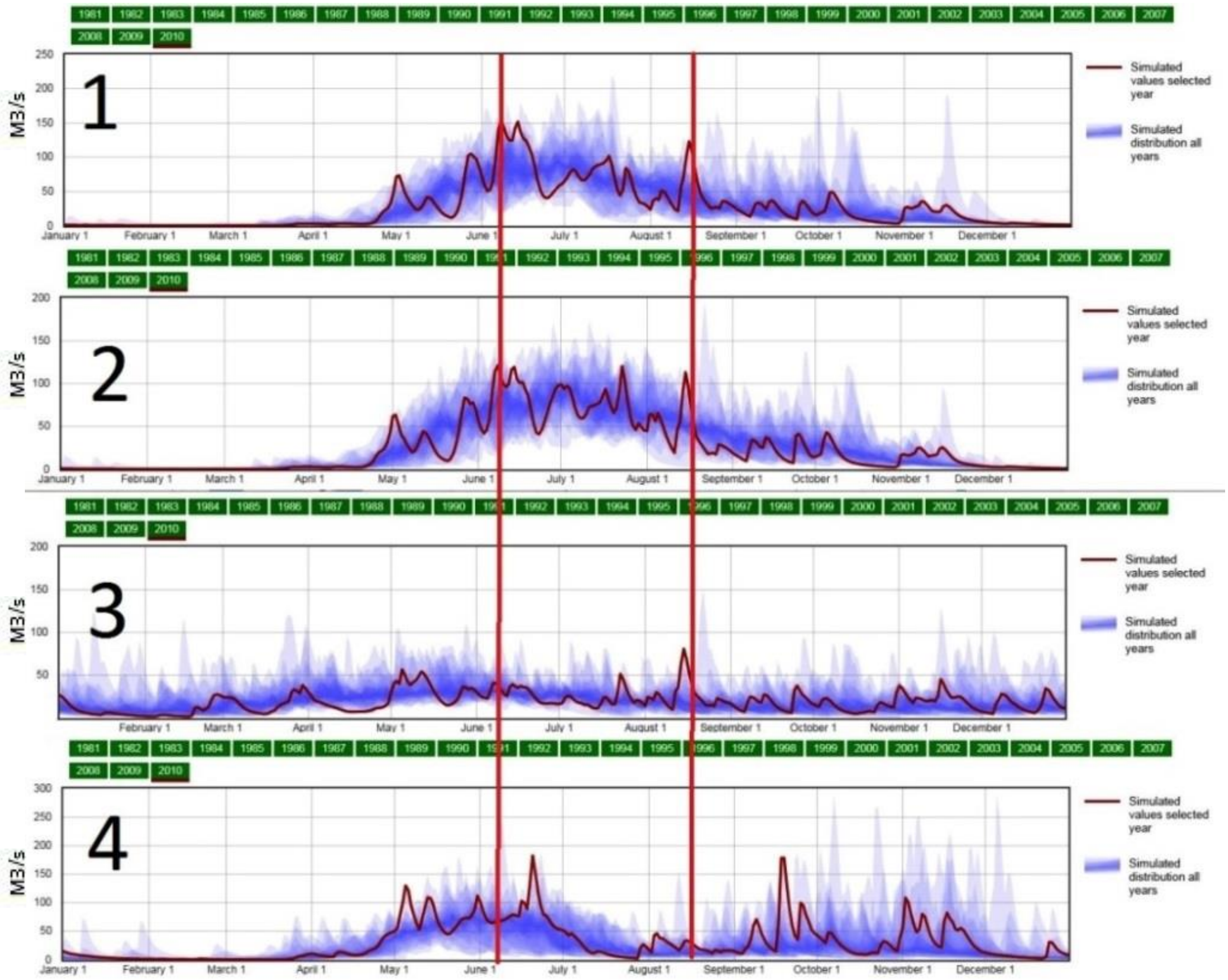

Figure 15. Comparison of water discharge peaks in the studied basins in 2010 (data provided by hypeweb.smhi.se)

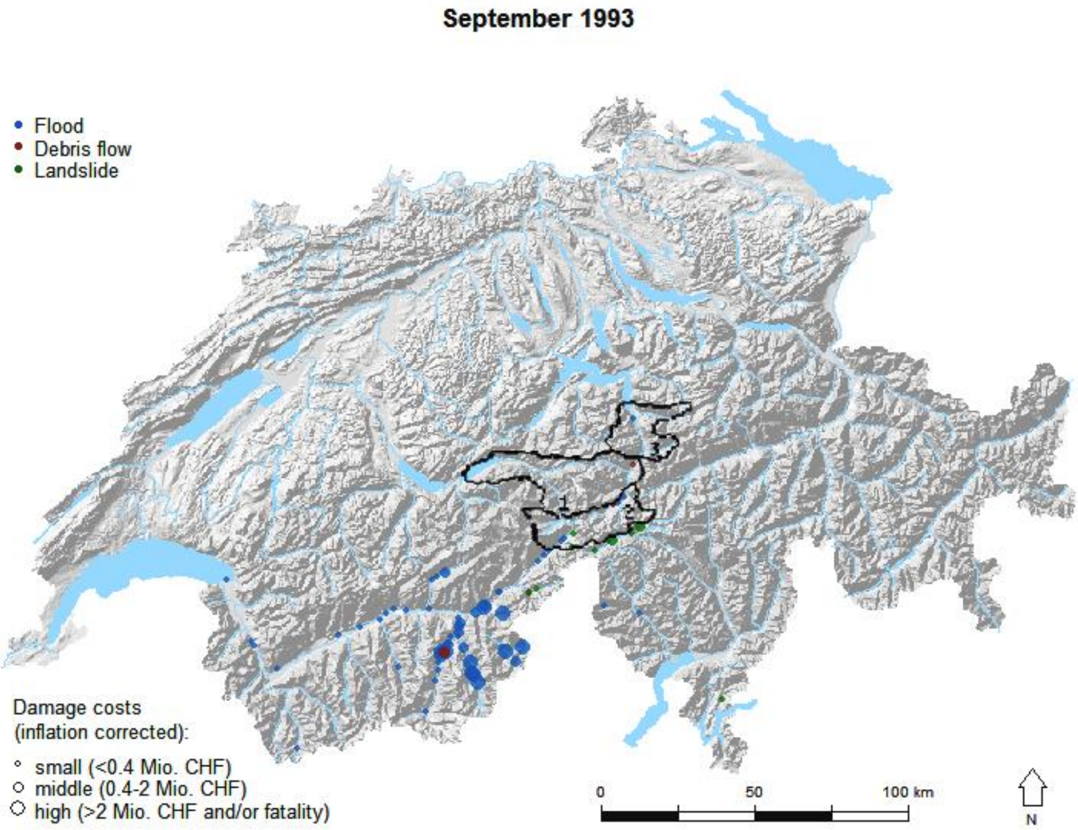

Figure 16. Flood and landslide damage events in September 1993

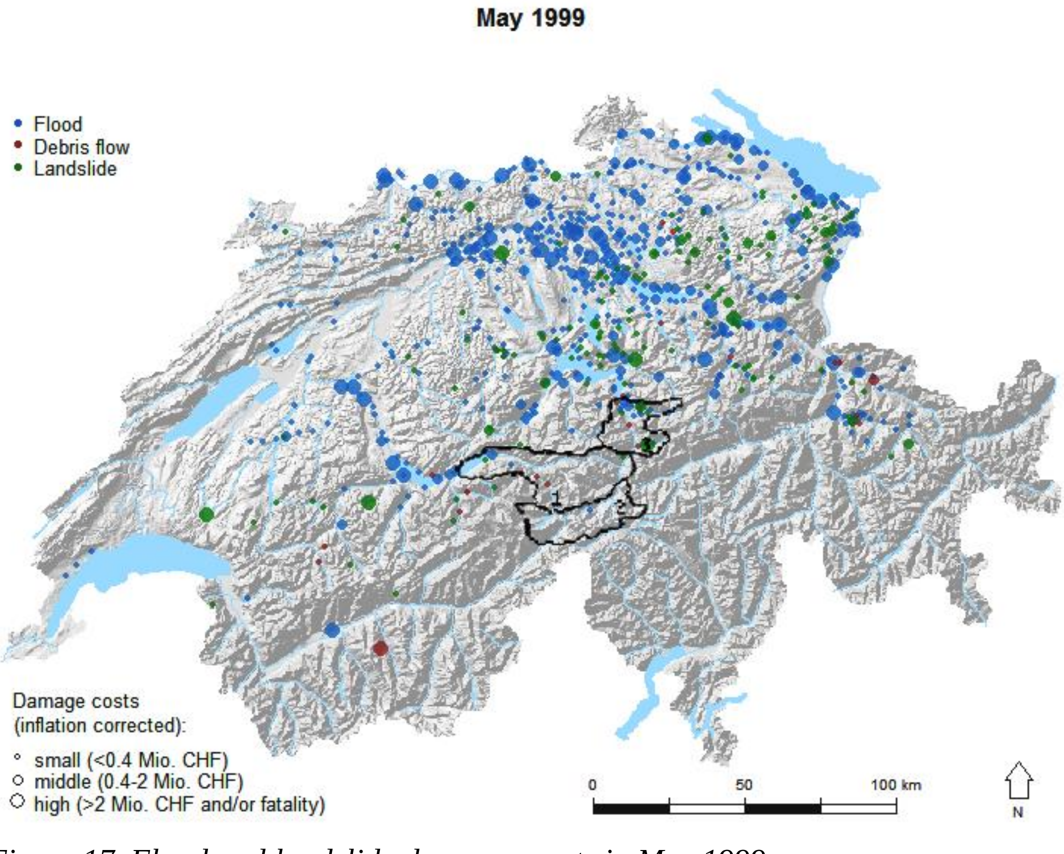

Figure 17. Flood and landslide damage events in May 1999

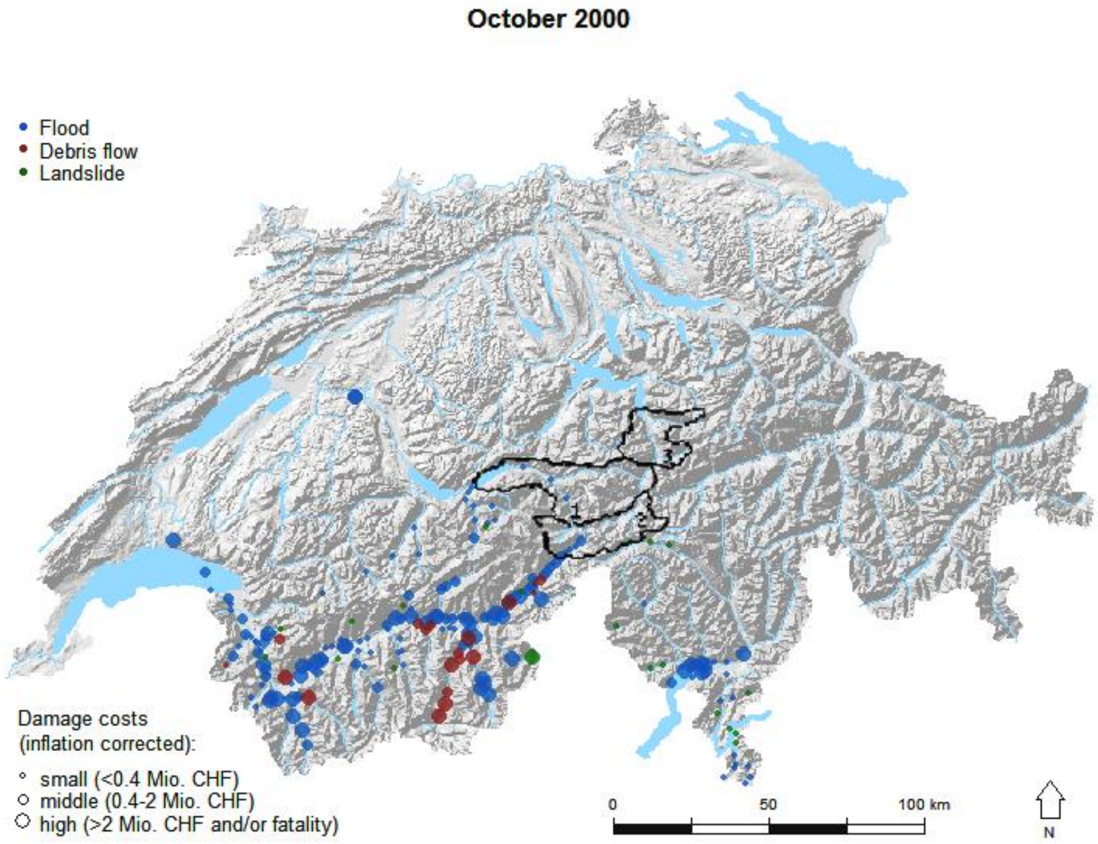

Figure 18. Flood and landslide damage events in October 2000

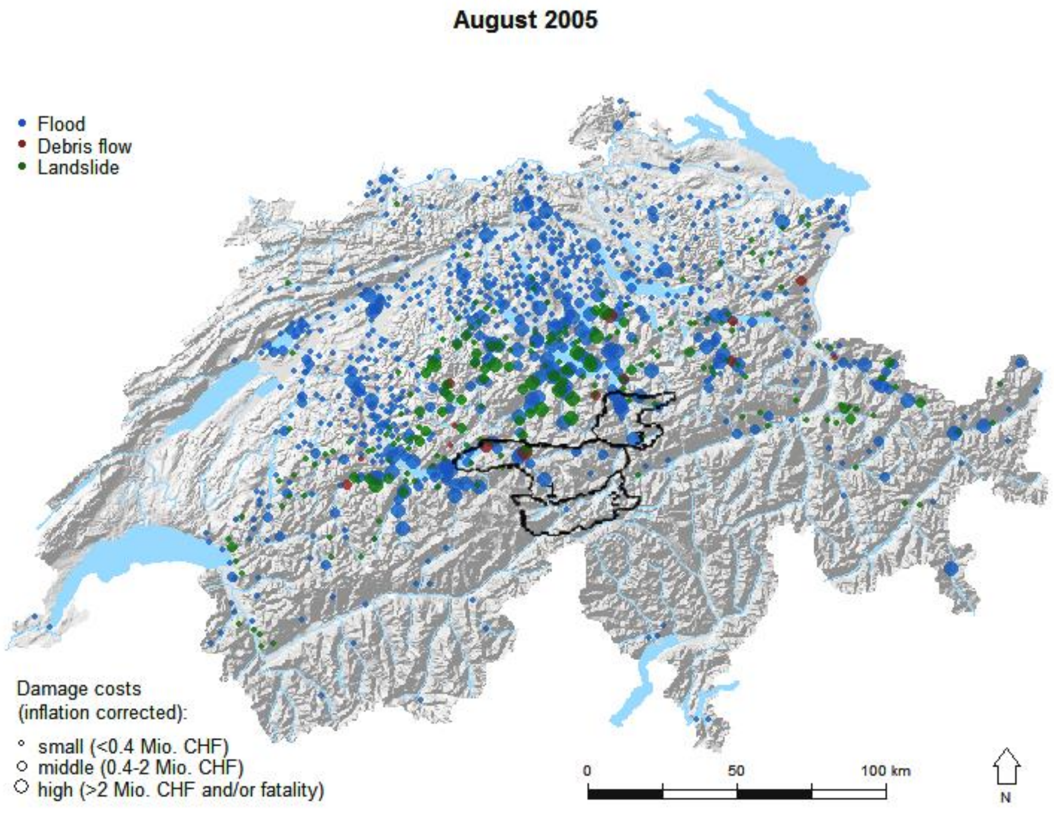

Figure 19. Flood and landslide damage events in August 2005

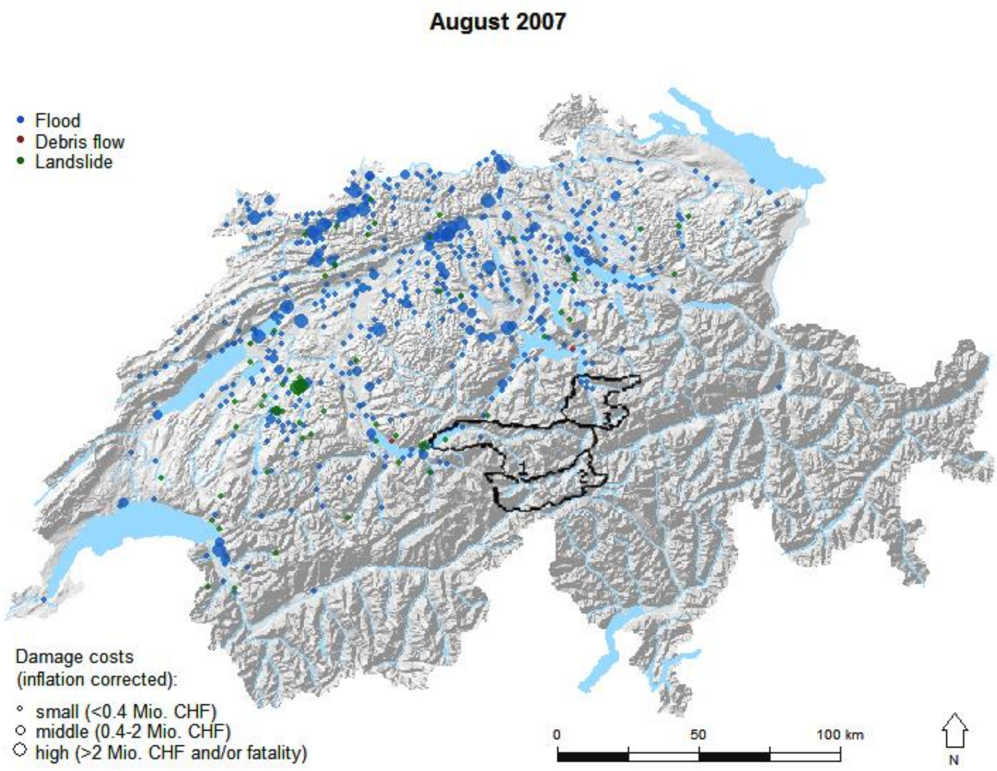

Figure 20. Flood and landslide damage events in August 2007

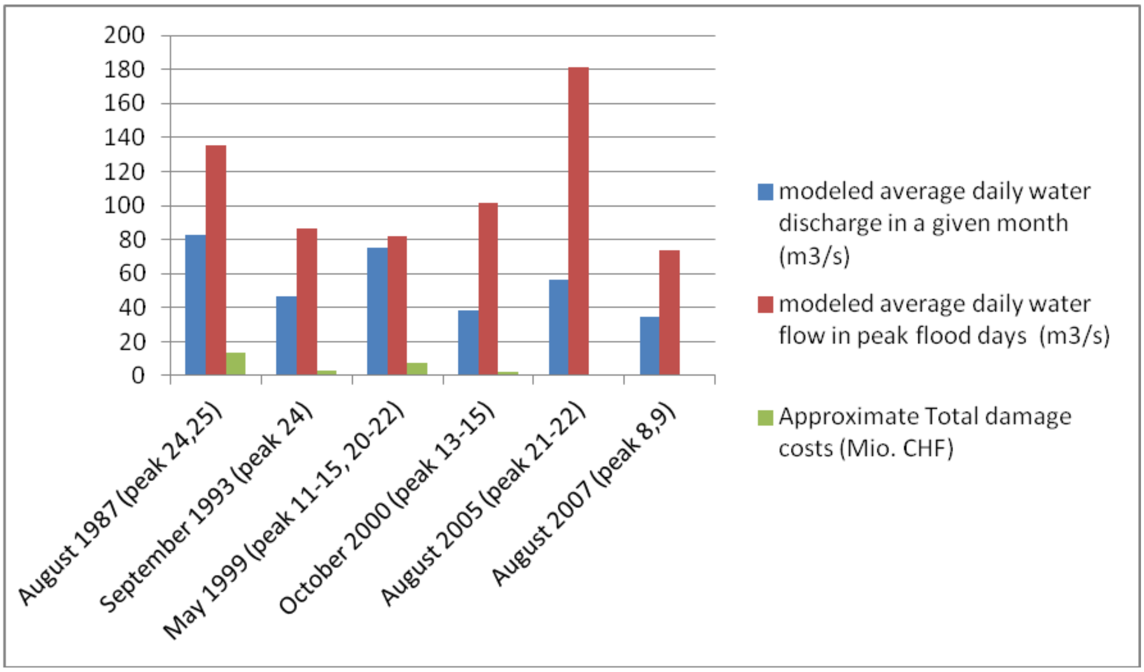

Figure 21. Comparison between the simulated river discharge and total damage costs in the upper reaches of River Rhone

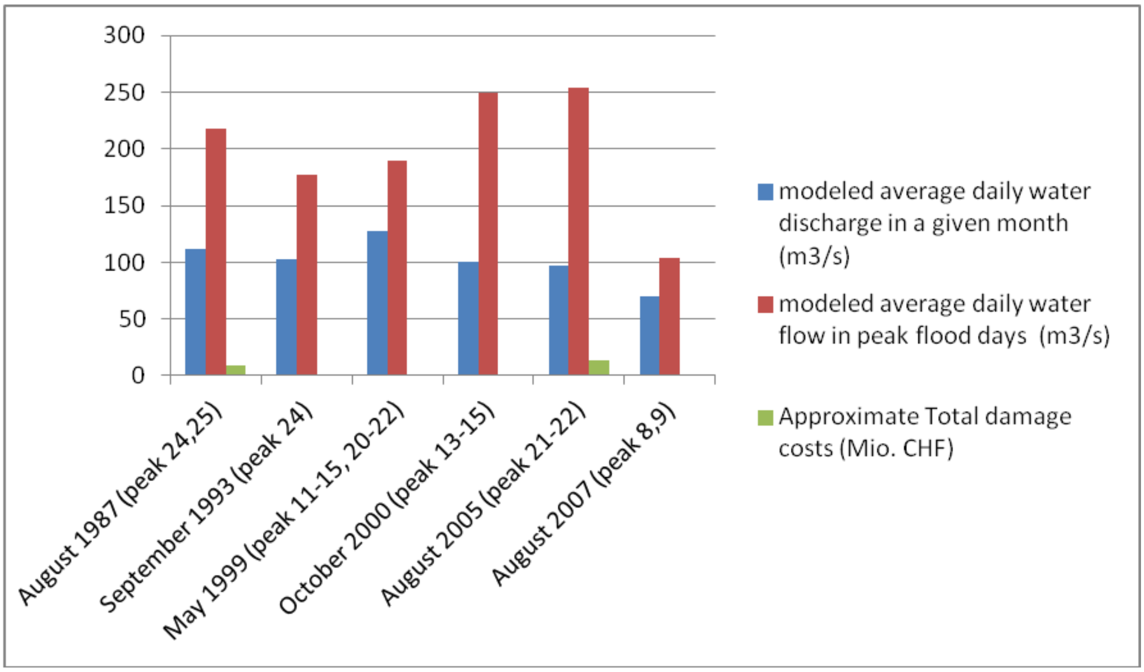

Figure 22. Comparison between the simulated river discharge and total damage costs in the upper reaches of Melhaa River

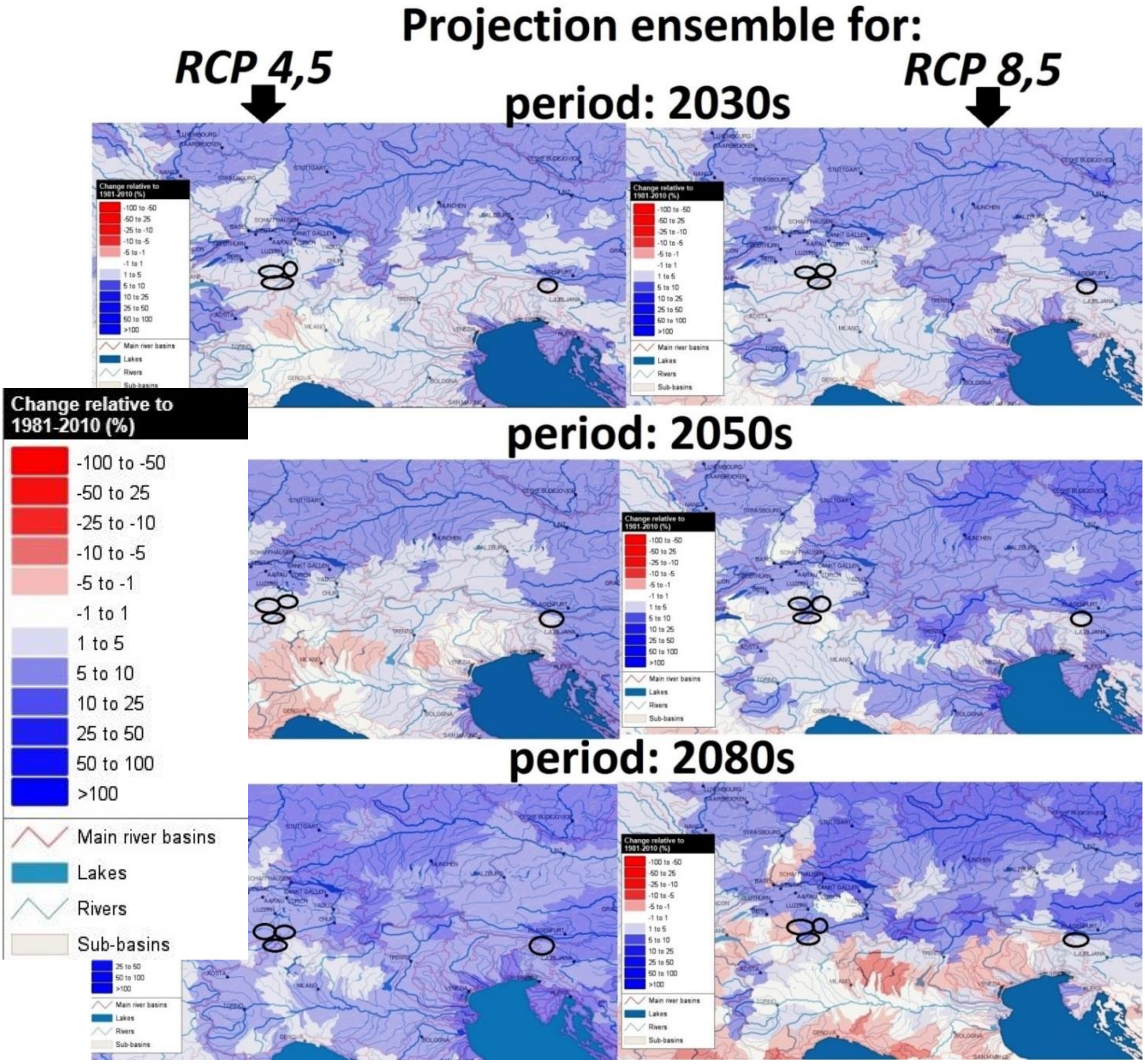

Figure 23. The simulated change in the amount of atmospheric precipitation according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s

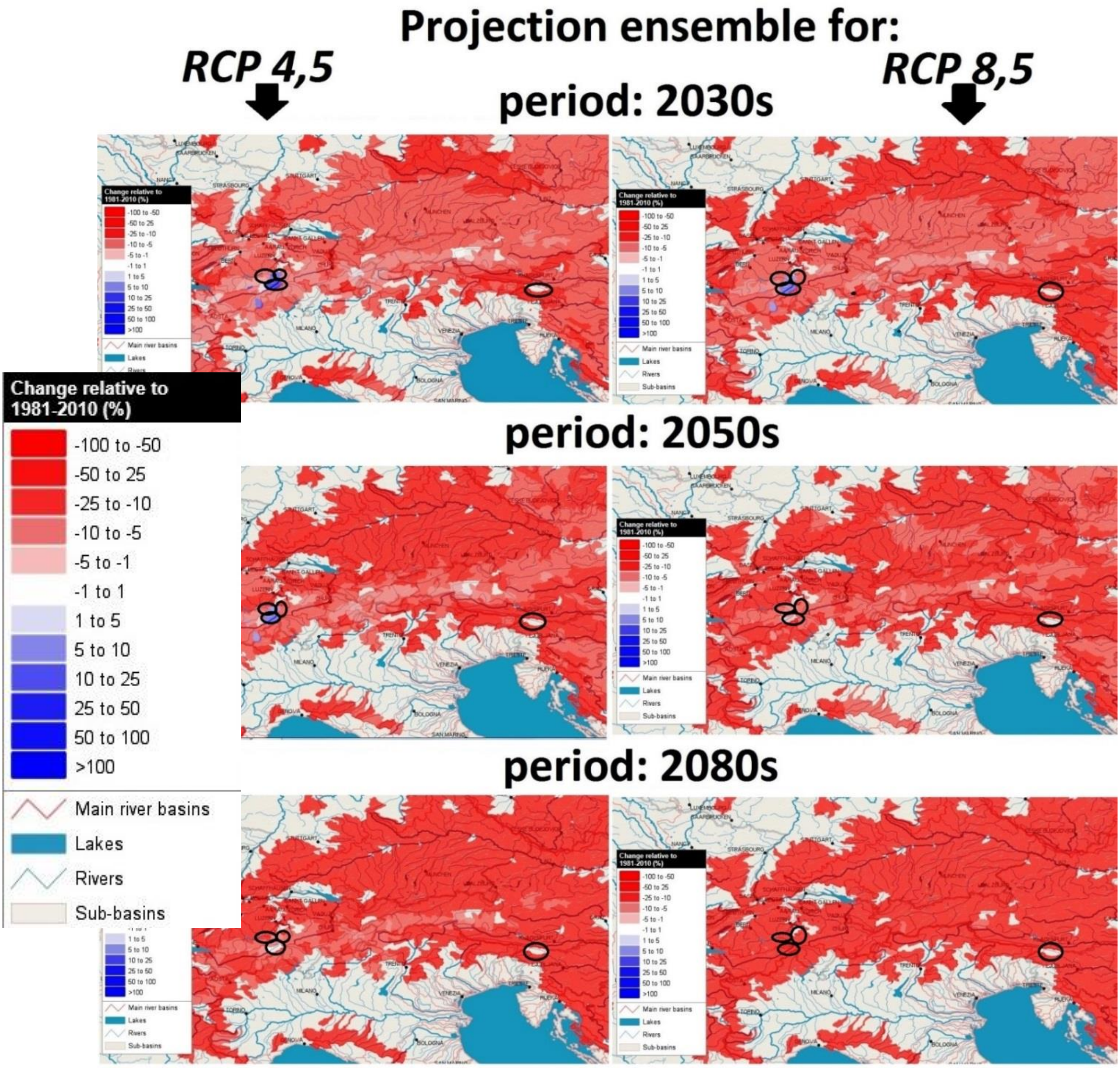

Figure 24. The simulated change in the snow water equivalent according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s

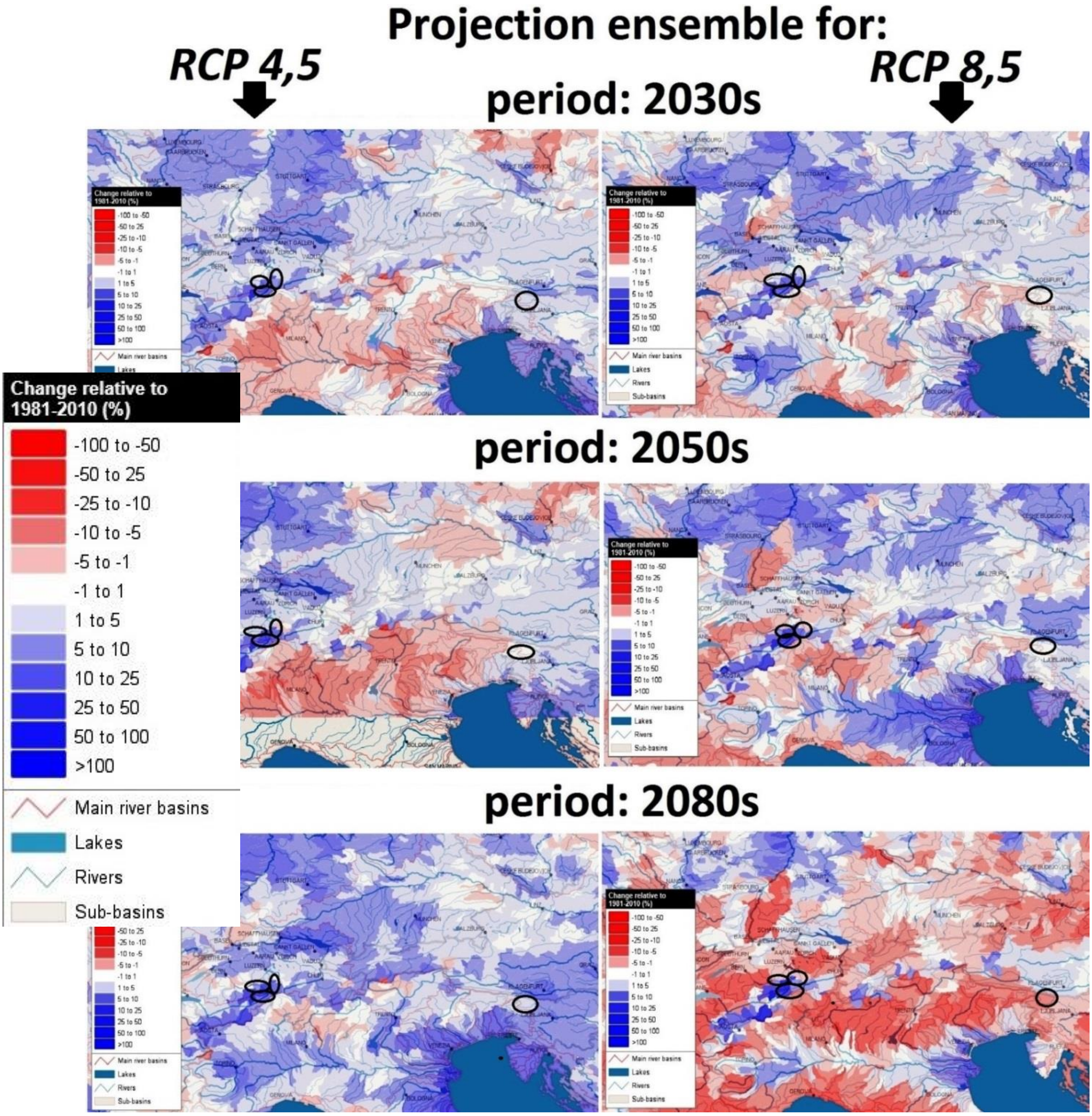

Figure 25. The simulated change in the total runoff from land according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s

Table 1. Comparison of water discharge peaks in the studied basins in 1981. Days with maximum water discharge are highlighted in color. (Fragment)

Date	River discharge (m3/s)		
	1. Aare river above Interlaken	2. Upper reaches of the river Ron	3. Upper reaches of the Melhaa river
1981-06-01	80.54709625	53.72829819	34.77690125
1981-06-02	92.51039886	66.20659637	34.0094986
1981-06-03	107.7817993	79.95490265	34.55830002
1981-06-04	114.0147018	80.15750122	35.59320068
1981-06-05	105.2982025	69.10929871	32.60710144
1981-06-06	100.5323029	66.09739685	30.0095005
1981-06-07	102.365303	70.41040039	29.38419914
1981-06-08	106.4682007	75.33699799	29.77890015
1981-06-09	122.2490005	90.95780182	33.37860107
1981-06-10	126.217598	93.91290283	34.91730118
1981-06-11	123.6677017	92.05470276	34.66270065
1981-06-12	120.9803009	91.50479889	33.40829849
1981-06-13	116.7263031	88.47160339	31.57559967
1981-06-14	115.7253036	89.61239624	30.81599998
1981-06-15	116.9452972	94.17980194	31.10750008
1981-06-16	116.4514008	94.3010025	30.55310059
1981-06-17	104.0466995	78.89849854	26.15399933
1981-06-18	88.65219879	64.09750366	20.79380035
1981-06-19	72.55789948	49.41730118	16.02300072
1981-06-20	57.65090179	37.02500153	12.85449982
1981-06-21	47.0318985	29.61849976	11.35990047
1981-06-22	40.23820114	26.22769928	10.69069958
1981-06-23	35.13619995	22.7451992	10.39220047
1981-06-24	33.90219879	24.68099976	11.54310036
1981-06-25	43.21450043	37.72610092	16.57119942
1981-06-26	57.38460159	52.40719986	22.83779907
1981-06-27	63.42679977	54.7983017	24.52300072
1981-06-28	110.8386002	99.10099792	51.05450058
1981-06-29	125.9972992	106.2391968	52.80939865

Table 2. Comparison between the simulated river discharge and total damage costs in the upper reaches of Melhaa River

Dates	modeled average daily water discharge in a	modeled average daily water	Approximate Total damage

	given month (m3/s)	discharge in peak flood days (m3/s)	costs (Mio. CHF)
August 1987 (peak 24,25)	111.72	217.99	9.4
September 1993 (peak 24)	102.56	176.91	0.2
May 1999 (peak 11-15, 20-22)	127.46	190	0.2
October 2000 (peak 13-15)	100.6	248.87	0.2
August 2005 (peak 21-22)	97.47	253.42	13.8
August 2007 (peak 8,9)	69.52	103.4	0.8

Table 3. The simulated change in the amount of Precipitation, Total runoff from land and River discharge according to the scenarios of the RCP 4.5 and RCP 8.5 during the periods of the 2030s 2050s and 2080s (basins: 1-Aare, 2-Rhone, 3-Melhaa, 4- Sava)

Periods of time and scenario	Precipitation (%)/(mm/year)				Total runoff from land (%)/(mm/year)				River discharge (%)/m^3/s			
Number of basin	1	2	3	4	1	2	3	4	1	2	3	4
Present time	2000-3000	2200-3200	2000-2500	1900-2200	2000-2250	2000-2250	2000-2250	1750-2000	10-25	50-100	100-500	50-100
2030s(4.5)	+1-+5	+1-+5	+1-+5	+1-+5	+10+25	+10-+25	+5-+10	+1-+5	+10-+25	+10-+25	+5-+10	+1-+5
2030s(8.5)	+1-+5	+1-+5	+1-+5	+1-+5	+10+25	+10-+25	+10-+25	-1-+1	+10-+25	+10-+25	+10-+25	-1-+1
2050s(4.5)	+1-+5	+1-+5	+1-+5	+1-+5	+5-+10	+25-+50	+5-+10	-1-+1	+10-+25	+10-+25	+5-+10	-1-+1
2050s(8.5)	+5-+10	+5-+10	+5-+10	+1-+5	+25-+50	+25-+50	+5-+10	-1-+1	+25-+50	+25-+50	+10-+25	-1-+1
2080s(4.5)	+1-+5	+1-+5	+1-+5	+1-+5	+5-+10	+10-+25	+5-+10	-1-+1	+10-+25	+10-+25	+10-+25	+1-+5
2080s(8.5)	+5-+10	+5-+10	+5-+10	+1-+5	+25-+50	+25-+50	+10-+25	-5--10	+25-+50	+25-+50	+10-+25	-5--10