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16. Hydrological and Limnological Perspectives in Times of Global Changes

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16. Hydrological and Limnological Perspectives in Times of Global Changes

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Swiss Society for Hydrology and Limnology (SGHL / SSHL),
Swiss Hydrological Commission (CHy)

16.1

Hydrological modelling under present and future scenarios in two alpine catchments

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This study intends to presents the main results of a two-year research that was done within the frame of a SNF Marie Heim-Vögtlin program that aimed to model the coupled hydro-geomorphologic system and to evaluate its hazard potential in two contrasting catchments, in south-western Switzerland under uncertainty and from the climate change perspective.

The study catchments are represented by the Avançon catchment (80 km^2), that include as head catchment the Vallon de Nant catchment - a natural reserve and the experimental basin of the Environmental and Geosciences Faculty from University of Lausanne, and the Tinte catchment (10km^2), a small catchment in the Verbier basin with a strong human impact.

One of the latest versions of the WASIM-ETH model (Schulla, 1997), that includes among others a glacier, snow, permafrost and slope instability modules, was used to simulate the water balance and slope instability in the two catchments at daily and hourly time steps. The uncertainty in the hydrological modelling was quantified by means of a Bayesian Monte Carlo Markov Chains approach (Balin et al, 2010, Balin et al, 2010). This approach enables computation of uncertainty due to the model parameters and the predictive uncertainty which includes in a lumped way other sources of uncertainty (i.e. input and model structure). The scenarios used in the present study are issued from the dynamic REMO-UBA regional model (Jacob, 2008) and will enable identifying the trend and the most important impacts of the changing climate on the hydro-geomorphologic hazards in two study catchments. The year 2050 has been chosen as projected horizon of the climate scenarios as (1) the climatic scenarios are more likely to happen and (2) this is more likely to interest the decision making and to influence the present challenges of the society in high alpine regions.

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16.2

The role of diffuse/direct radiation partitioning in land-atmosphere interactions and terrestrial water cycling

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The nature of light (diffuse or direct) and not only its quantity is important for ecosystem functioning. In particular plant photosynthesis is sensitive to the partitioning between diffuse and direct light. This has implications not only for the carbon cycle but also for water cycling, since photosynthesis is tightly coupled to plant transpiration.

In order to quantify the effect of diffuse/direct radiation partitioning on surface fluxes and climate, we use the newly developed COSMO-CLM^2 model. COSMO-CLM^2 is a coupled biosphere-atmosphere Regional Climate Model (RCM) combining the COSMO-CLM atmospheric model and the NCAR Community Land Model. An evaluation of the model against observations will first be presented.

A set of diffuse/direct radiation partitioning experiments over Europe will then be analyzed. Two situations are compared: a first situation where the proportion of diffuse versus direct light (constituting surface incoming shortwave radiation) is set constant temporally and spatially; a second situation where the land model explicitly receives diffuse and direct shortwave components as calculated by the atmospheric radiation scheme. Comparison with observations reveals that the atmospheric radiation scheme provides a rather realistic description of diffuse/direct radiation partitioning at the surface (more direct light in summer compared to winter, more diffuse light with increasing latitude, etc). This in turn has a strong influence on photosynthesis and transpiration. However, the effect on total evapotranspiration is limited, due to the existence of a compensating mechanism involving ground evaporation. For this reason the overall impact on the European climate remains relatively small. We note however that the effect of diffuse/direct radiation partitioning might be stronger for more productive ecosystems such as tropical forests. To shed some light on this question, similar experiments over Africa are currently under way.

16.3

Aquatic organisms as indicators of past climate variability

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Aquatic organisms such as chironomids (non-biting midges), diatoms and chrysophytes (golden-brown algae) are known to be sensitive to changes in e.g. lake water chemistry, nutrient levels and the availability of light. However, they may also be highly sensitive to air temperature, which makes the sedimentary remains of these organisms very promising proxies for climatic reconstructions. The head-capsules of chironomid larvae are generally well-preserved in lake sediments. Since the temperature optimum and tolerance range of these are known for the Swiss Alpine region, these can be used to reconstruct past July temperatures (Larocque-Tobler et al., 2010). Chrysophyte algae produce siliceous cysts that are also preserved in lake sediments. Previous work in the Austrian (Kamenik and Schmidt, 2005) and Swiss (De Jong and Kamenik, *in press*) Alps and the Pyrenees (Pla and Catalan, 2005) has demonstrated their sensitivity to cold-season temperatures. The total biogenic silica (bSi) content of sediment samples was also shown to be a potential proxy for June-July-August temperatures (Trachsel et al., *in press*).

In these studies (Larocque-Tobler et al, 2010; De Jong and Kamenik, *in press*; Trachsel et al., *in press*) detailed analyses of bSi, chrysophyte cysts and chironomid head capsules were conducted on the varved sediments of Lake Silvaplana (Engadine, 1800 m asl). Here we present a reconstruction of winter and summer temperatures covering the past 1000 years at near-annual resolution. Comparison to independent records (meteorological timeseries, other proxy records) shows that these methods yield excellent results for the Alpine region (Fig. 1). This study clearly highlights the potential of aquatic organisms as proxies for past temperature variability.

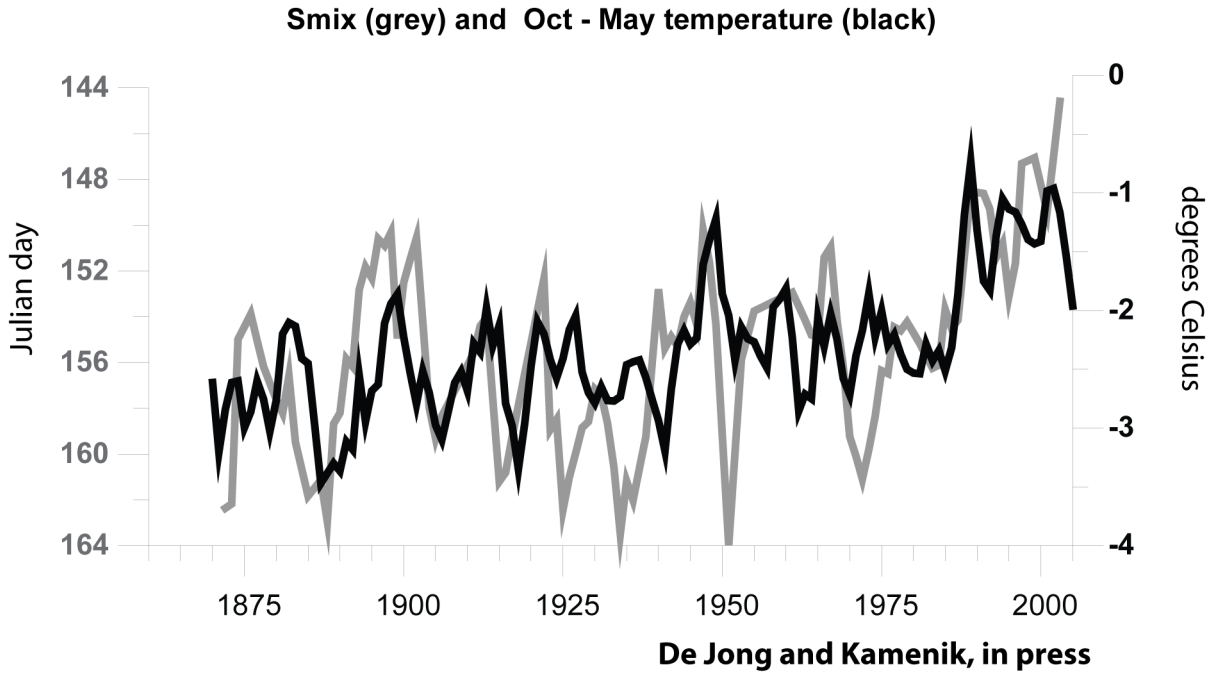

Figure 1: Comparison of reconstructed climate parameter Smix (date of spring mixing, based on chrysophyte stomatocysts, grey line) with measured Oct- May temperatures from Sils Maria (black line) (from De Jong & Kamenik, *in press*)

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16.4

Landscape transformation of an Alpine floodplain influenced by humans: Historical analysis from aerial images

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Natural floodplains are among the most productive and biologically diverse ecosystems worldwide, but they are also among the most endangered due to climate change and human impacts such as water storage, flood control and hydro-power production (Tockner & Stanford, 2002). Floodplains are composed predominantly of different aquatic (e.g. channel and pools) and terrestrial (e.g. riparian forests, islands, gravel bars) habitats affected by major hydrological forces that shape habitat heterogeneity and distribution, and channel migration and turnover (Whited. et al., 2007). Despite their highly dynamic nature, the relative abundance of different habitat elements in natural floodplains seems to remain more or less constant over ecological time periods. This phenomenon is also described as the “shifting mosaic steady state” by Ward et al. (2002). Therefore, spatial changes in habitat heterogeneity and abundance can be used to quantify the effects of human interference such as from flow regulation and water abstraction that have profoundly changed most braided alpine floodplains (Kollmann et al., 1999). We investigated the spatio-temporal transformation of floodplain habitats and channel complexity for a 3.4-km long and up to 600-m wide alpine floodplain (Sandey, Innertkirchen, Canton Bern, 850 m a.s.l.) from its near natural state in 1940 to 2007 by analyzing a series of historical aerial images. Indices such as the

braiding index (Thalweg length main channel/ thalweg length main and side channel) and shoreline length ratio (shoreline length/river length) were derived from the analysis. Within this time period, the floodplain was subject to several hydrological and morphological modifications that included water abstraction (ca. 30 % of average annual discharge) in the upper catchment (from 1950) and the construction of several levees within the active floodplain. Results showed that habitat heterogeneity and channel complexity changed substantially between 1940 and 2007. We could distinguish two main time periods of change. First, a period from 1940 to 1986 with strong decreasing habitat heterogeneity, e.g. more than 90% of island area lost and parafluvial areas (gravel areas without established vegetation that are frequently flooded) decreased by about 34%. Channel complexity was also reduced as indicated by the braiding index and shoreline length ratio changing from 1.8 to 1.3 and 3.1 to 2.4, respectively. Second, a period from 1986 to 2007 when habitat heterogeneity and channel complexity partly recovered. Islands were reestablished in the system (area increase of 50%) and the parafluvial area increased by about 64%. The braiding index and shoreline length ratio increased to 1.6 and 2.9, respectively. This increase in habitat heterogeneity and channel complexity parallels an increasing yearly frequency of high precipitation events (> 60 mm 24 h^{-1}) in the region. However, habitat and channel conditions are still below the status before floodplain impairment by humans. The study clearly demonstrates the negative effect of water abstraction and flood protection on habitat heterogeneity and channel complexity of the floodplain but also raises the question whether elevated frequencies of high flow events induced by climate change can contribute to floodplain restoration.

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16.5

Modelling Global Changes Impacts on the Black Sea Catchment

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The Black Sea Catchment is recognized for for its great historical and cultural value, but also for its ecologically unsustainable development and inadequate resource management leading to severe environmental, social and economical problems. The EU FP7 EnviroGRIDS @ Black Sea Catchment project (www.envirogrids.net) is addressing these issues by bringing several new emerging information technologies that are totally revolutionizing the way we will be looking at our planet in the future. The aim of the project is to build capacities in the Black Sea region to use new international standards to gather, store, distribute, analyze, visualize and disseminate crucial information on past, present and future states of this region, in order to assess its sustainability and vulnerability. To achieve its objectives, EnviroGRIDS will build a Grid-enabled Spatial Data Infrastructure (gSDI) serving data, information and services in the Global Earth Observation System of Systems (GEOSS), and being compatible with the European directive on Infrastructure for Spatial Information in the European Union (INSPIRE), as well as the United Nations Spatial Data Infrastructure (UNSDI). EnviroGRIDS will particularly target the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR) in order to help bridging the gap between science and policy.

The scientific aim of the EnviroGRIDS project is to start building an Observation System that will address and assess several GEOSS Societal Benefit Areas under global changes. This system will incorporate a shared information system that operates on the boundary of scientific/technical partners, stakeholders and the public. It will contain an early warning system able to inform in advance decision-makers and the public about risks to human health, biodiversity and ecosystems integrity, agriculture production or energy supply caused by climatic, demographic and land cover changes on a 50-year time horizon.

To achieve and support the vision and objectives of enviroGRIDS, the gSDI (currently under development) will provide interoperable and standardized data storing, discovery, accessibility and retrieval as well as processing capabilities based on the Grid infrastructure of the Enabling Grids for E- SciencE (EGEE) project. In consequence, one of the key challenges

of the enviroGRIDS project is to bridge the technological gap between SDIs and Grid infrastructures and to make these infrastructures interoperable. In its four-year timeframe (started in April 2009), enviroGRIDS aims to benefit from the EGEE infrastructure to run a high resolution (spatially and temporally) water balance model on the entire Black Sea catchment (2.1 mio. square km.) using the Soil and Water Assessment Tool (SWAT). The project will also implement methods to access and process near real-time data from sensors and satellite images allowing to develop early warning systems and decision support tools. In term of analysis capacities, this will offer the possibility to shift from a traditional single desktop computer to sizable computing resources, allowing environmental scientists to leverage the full potential of high-resolution spatio-temporal data sets. The EnviroGRIDS gSDI will probably be one of the first implementation of such a grid-enabled infrastructure in a trans-national framework.

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16.6

Hydrodynamics of Lake Geneva inferred from Stable H- and O-Isotope Compositions

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The expected increase of average annual temperatures and changes in precipitation patterns linked to the changes in climate, but also the human influence in terms of surface runoff and waste water inputs, may alter the physical, chemical, and biological dynamics of a lake and could thus affect future water quality in ways that are still unknown. Because the stable H- and O- isotope compositions of water are clearly linked to temperatures of precipitation from the ambient air mass and the origin of the air mass, variations in the H and O isotopic compositions as a function of time and place within a big lake such as Lake Geneva may help to interpret changes in its hydrology and dynamics of the water budget. The main research goal of this study is to evaluate the variability of the H- and O-isotope composition of Lake Geneva in order to apply it to a qualitative and quantitative assessment of the water budget.

Lake Geneva, Europe's largest freshwater reservoir located in a temperate climate zone, is mainly recharged by the Rhone river (~ 75%). Given the large volume (89 km^3, maximum depth 310 m) and long residence time of water (~11.4yrs), its dynamic system, that is the interaction with surface and underground in/out-flows, precipitation, and evaporation fluxes may well be complex. Results from water samples and CTD profiles taken from morphometrically different basins of the lake in August 2009 (Fig.1) indicate a stratified water body. The epilimnion (uppermost 2-12 m) is relatively enriched in ^{18}O with $\delta^{18}O$ values between -11.8 and -12.1‰ at the water surface. All profiles show a progressive depletion in ^{18}O with depth, reaching minimum values in the middle of the metalimnion (20 m) of between -12.4 and -12.8‰ .

In the lower part of the metalimnion (20-40 m) the water becomes increasingly enriched in ^{18}O with depth again (-12.1 and -12.3‰), reaching more or less constant values in the hypolimnium. However, winter profiles taken in March 2010 are homogenous in all sampling points and layers (-12.3‰).

The difference in the isotope composition is related to the thermal stratification of the lake and mixing of glacial-sourced Rhone water, which has an average isotope composition of -13.9‰. Plotting all available isotope data from the watershed also indicates that water samples from the metalimnion are located between the Rhone and lake water on the LMWL. Rhone water can thus be traced to move through the lake over 50km as a stream in the thermocline/chemocline region. This phenomenon, previously described already as „La bataillère“, represents a cold silt-laden density current of glacial Rhone meltwater, which has a low content of dissolved solids and is therefore producing water of an intermediate density (Gorceix & Kreitmann 1930).

To better understand the extension of this stream, four cross sections of water profiles were taken in the lake in a second sampling campaign in August 2010. The results show the same curved progression of isotopic variation with depth as in the year before and demonstrate that the stream is also extending to relatively shallow bay regions. In comparison to August 2009, where the samples most depleted in ^{18}O and D were found at about -20m, those most depleted in these isotopes in August 2010 were found at -10m at the same sampling points. This difference can be explained as 2010 was influenced by more windy and cooler weather conditions than the year before, which results in a shallower thermocline region than the year before.

In contrast to the isotopic compositions, the results from the major ion analyses indicate that the lake water and its different sources are well-mixed as the variations are smaller than the analytical errors associated with the analyses via liquid chromatography. This underlines the sensitivity and strength of the application of stable isotopes in order to evaluate mixing of different waters and in contrast to other methods, like turbidity measurements, this method allows for a direct, natural tracing of the water sources and hydrodynamics of Lake Geneva. In order to apply the results to a qualitative and quantitative assessment of the water budget one further sampling campaign will be conducted in fall 2010 to trace the seasonal mixing of the water layers. In addition, water samples were also analysed for micropollutant concentrations and it is planned to evaluate correlations between these and the isotope compositions in order to trace micropollutant fate in the lake.

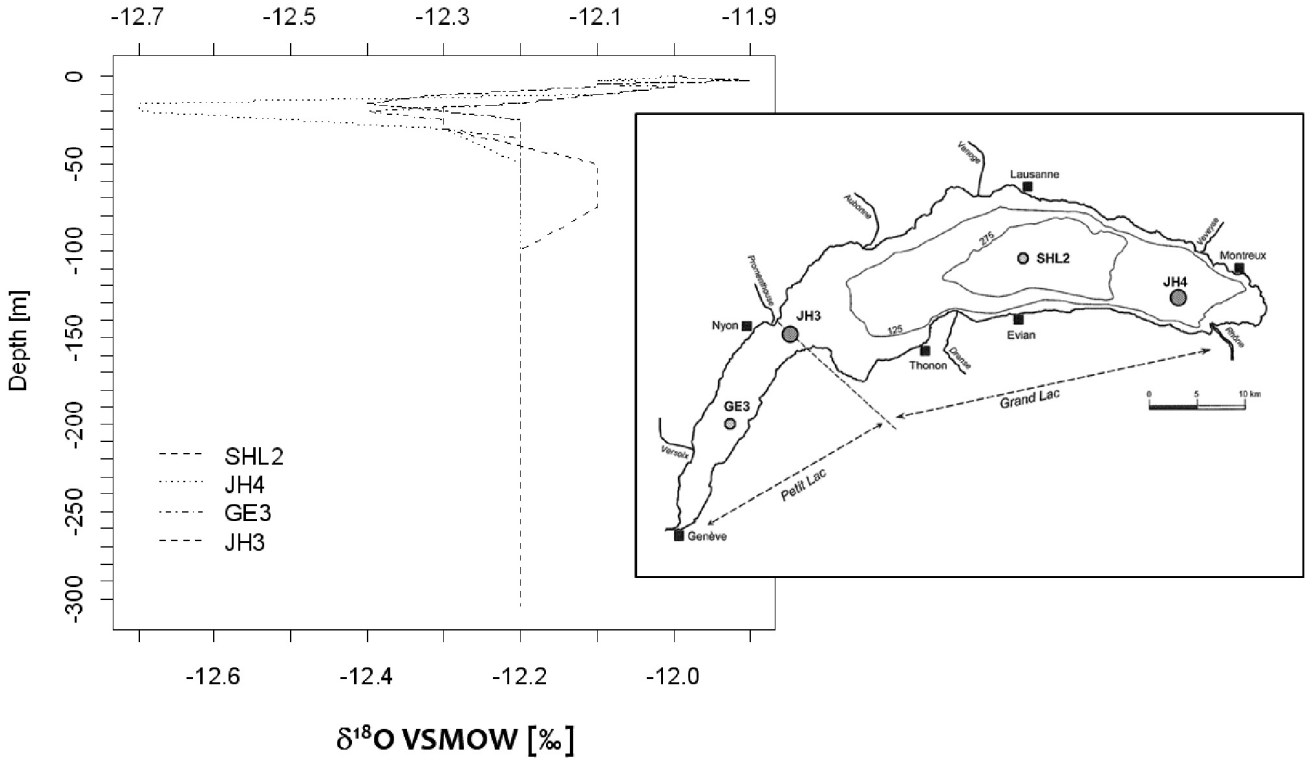

Figure 1.: $\delta^{18}O$ values in relation to depth of four sampling points in Lake Geneva (August 2009).

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16.7

Life-history plasticity in a detritivore determines ecosystem response to climate warming

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Many ectotherms grow faster in warmer environments. However, life history tradeoffs in growth rate, body size, and fecundity can constrain the influence of warming on an individual's resource consumption. Additionally, although warmer temperatures can cause phenological shifts in some species, changes in the timing of resource demand may vary across taxa, functional groups, and trophic levels. Using a randomized complete block 2x2 factorial field enclosure experiment, we examined the consequences of increased temperature (+4˚C, ambient), and resource availability (nitrogen subsidized, ambient) on littoral zone communities feeding on *Phragmites australis* leaf litter. We find that life history plasticity of a key benthic consumer (*Limnephilus spp.*, Trichoptera) in response to climate warming can strongly affect rates of leaf litter decomposition. However, community dynamics can buffer species specific responses. Our results demonstrate that experimental field studies that capture species responses in complex communities will be necessary to accurately predict the effects of climate change on ecosystem functioning.

16.8

Approaching water stress in the Alps- Water management options in the Crans-Montana-Sierre region, Valais (MontanAqua): estimation of available natural water resources

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The main objective of the current transdisciplinary project is to develop strategies moving towards a more sustainable water resources management in the Crans-Montana-Sierre region (Valais), together with actors involved. The study region is situated in the driest part of Switzerland and has been subject to dynamic economic, tourism and urban development during the last decades. The proposed research on more sustainable water management options will evaluate co-ordination and adaptation of water demand to water availability under changing biophysical and socioeconomic conditions.

For the detailed assessment of the available water resources in the study area, today and in the future, two distinct sources of water must be considered: (1) the in-situ water resources resulting from the natural water balance; (2) water which is transferred from different sources (e.g. glaciers, reservoirs) through the system by natural flows (rivers, subsurface flows) and by artificial channels within the irrigation scheme.
The study area is highly differentiated across the altitudinal range, and does not cover a classical hydrological basin as the water flows frequently across natural hydrographic boundaries, what is a big challenge from a hydrological point of view. Assessment of present hydrological conditions by observation will be the basis for establishing a detailed hydrological model for the entire study region (sub-module MODEL). In-depth assessment of the present and future availability of water will allow identifying areas with water surplus and deficits respectively. Results will be strongly related to the issue of evaluating the impact of different land use practices.
In the higher parts of the area, snow is a major hydrological element, which is highly sensible and is expected to be significantly affected by climate change. The Plaine Morte, a typical plateau glacier situated on the main divide between the cantons of Berne and Valais, seems to be an important water resource for the region, will also be sensitive to climate change. Despite the geological investigation of Wildberger [Wildeberger, 1981] and a few glaciological investigations, its role as well as the influence of its karstic environment in the water balance is still not fully understood and remains uncertain.
Therefore the role of snow (sub-module MODEL) and ice (sub-modules GLACIER and KARST with external collaboration), both valuable water sources for the region, will be thoroughly investigated.

The finite volume method conserves mass and as such is more appropriate for hydrological applications and for the estimation of available water resources.
Besides the choice of approach, a fundamental problem of modelling water balance is that often many of the equations we use to represent processes require calibration, thus their parameters cannot be directly measured.
This is true even of ''physically based'' equations because they are invariably applied at a scale different to that at which they were derived [Graysonetal., 2000].
It should be stressed the limited possibilities to calibrate-validate a model in the region based on historical data, due to the lack of extensive discharge and soil moisture measurements. What in turn reduces margins of conceptualization of the processes occurring in the region, as well as penalizes any need for parameter estimation.

Therefore the Penn State Integrated Hydrologic Model (PIHM) has been selected for the estimation of water resources in the study area,
It is a semi-discrete, physically-based model which includes: channel routing, overland flow, subsurface saturated unsaturated flow, rainfall interception, snow melting and evapotranspiration (refer to Fig.1).

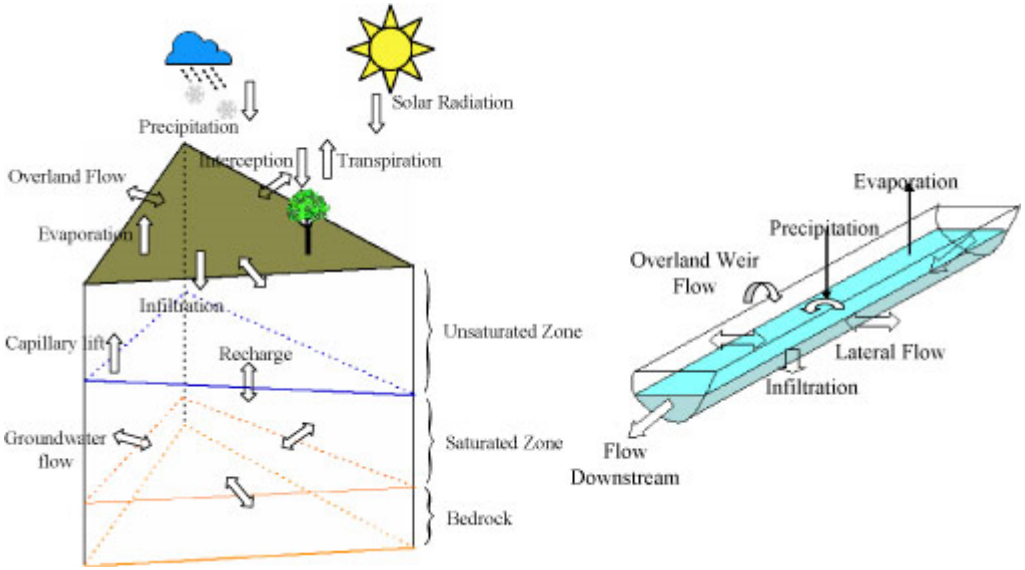

Fig.1: All the interacting hydrologic processes in PIHM are defined on prismatic watershed elements or linear river elements. ODEs corresponding to each process from all across the model domain are solved together to predict state variables at next time step. (source http://www.pihm.psu.edu/pihm_home.html)

In principle the domain is decomposed using the catchment boundary and stream network as constraints, however the choice of including other thematic maps for the catchment decomposition is left to the user.
The 2-D TIN is vertically projected creating prismatic volumes. The prismatic volume is divided into layers and a local system known as the kernel is created in which all the relevant hydrological processes occur within the prismatic volume. Hydrological processes are governed by both ordinary differential equations (ODEs) and partial differential equations (PDEs). PDEs are reduced to ODEs using the semi-discrete method, also known as the finite volume method. Coupling between elements is controlled by the fluxes across the boundary element [Minogue, 2008].

Some of the parameters are fixed with values obtained from the literature and extensive calibration is performed only for a limited number of parameters to which the model is the most sensitive. This allows a 'constrained' calibration [Ivanovetal, 2004], which will be based on case studies, where historical data are available, as well as on the dense measuring network built within the framework of the project.

The progressing of the understanding of catchment processes and system behaviour for the assessment of currently available water resources will allow landuse change scenarios and related consequences to be coupled in a comprehensive potential climate-change impact assessment, addressing sensitivity and uncertainty of the proposed scenarios as well as corresponding results.

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16.9

Hydrological change in Switzerland: Which catchments are most sensitive? - A comprehensive assessment of climate change impact

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We assess future impacts of climate change on hydrological systems in Switzerland through hydrological modelling with the semi-distributed and conceptual yet process-oriented PREVAH model (Viviroli et al. 2009), that we force with scenario data as climate input.

The anticipated climate change in Switzerland will result in changing precipitation patterns and increasing temperatures, and these changes will have an impact on the hydrological systems. The objective of our study is to determine those catchments that exhibit sensitivity towards a change in climate, and to identify specific catchment characteristics causing this sensitivity. Both issues will be addressed in the framework of the joint research project "Climate Change in Switzerland – Hydrology" (CCHydro, Volken 2010).

We apply climate scenarios of expected changes (deltas) in the annual cycle of temperature and precipitation. For each day of the year and observational station site, the delta between the control (1980–2009) and the scenario periods (2021–2050, 2070–2099) is provided (Bosshard et al. in preparation). For every site, a total of 10 model chains from the ENSEMBLES-project (Hewitt & Griggs 2004), each consisting of one general circulation model (GCM) driving one regional climate model (RCM), were analyzed. All model chains assume the SRES A1B emission scenario. Differences between the 10 different model chains represent modelling uncertainty.

The annual cycle of expected changes is superimposed on the observed time series to generate a set of climate scenarios with which the models for the catchments considered are forced. The hydrological modelling system PREVAH is run with hourly meteorological input and on basis of a spatial resolution of 500 x 500 m^2. Thus, we examine approximately 200 mesoscale catchments with an average area of 150 km^2 and a range of 30 to 2000 km^2 to specify process-based relationships between climate sensitivity and specific catchment characteristics. An application of climate scenarios to such an extensive set of catchment models that are processed at this spatial and temporal resolution is new so far. This approach is, however, necessary to meet the high degree of heterogeneity of mountainous environments as well.

In addition, changes in land use, i.e. an alteration of glaciated and forested area, will be included in the framework to study the respective impacts on the hydrological systems.

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16.10

Rainfall distribution is the main driver of runoff under future CO_2-concentration in a temperate deciduous forest

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Reduced stomatal conductance under elevated CO_2 results in increased soil moisture, provided all other factors remain constant. Whether this results in increased runoff critically depends on the interaction of rainfall patterns, soil water storage capacity and plant responses. To test the sensitivity of runoff to these parameters under elevated CO_2, we combine transpiration and soilmoisture data from the Swiss Canopy Crane FACE experiment (SCC, 14 30–35m tall deciduous broad-leaved trees under elevated CO_2) with 104 years of daily precipitation data from an adjacent weather station to drive a three-layer bucket model (mean yearly precipitation 794mm). The model adequately predicts the water budget of a temperate deciduous forest and runoff from a nearby gauging station. A simulation run over all 104 years based on measured sap flow responses resulted in only 5.5mm (2.9%) increased ecosystem runoff under elevated CO_2. Out of the 37 986 days (1 January 1901–31 December 2004), only 576 days produce higher runoff in the elevated CO_2 scenario. Only 1 out of 17 years produces a CO_2-signal 420mma_1, which mostly depends on a few single days when runoff under elevated CO_2 exceeds runoff under ambient conditions. The maximum signal for a double preindustrial CO_2-concentration under the past century daily rainfall regime is an additional runoff of 46mm. More than half of all years produce a signal of o5mma_1, because trees consume the 'extra' moisture during prolonged dry weather. Increased runoff under elevated CO_2 is nine times more sensitive to variations in rain pattern than to the applied reduction in transpiration under elevated CO_2. Thus the key driver of increased runoff under future CO_2-concentration is the day by day rainfall pattern. We argue that increased runoff due to a first-order plant physiological CO_2-effect will be very small (<3%) in a landscape dominated by temperate deciduous forests, and will hardly increase flooding risk in forest catchments. Monthly rainfall sums are unsuitable to realistically model such CO_2 effects. These findings may apply to other ecosystems with comparable soil water storage capacity.

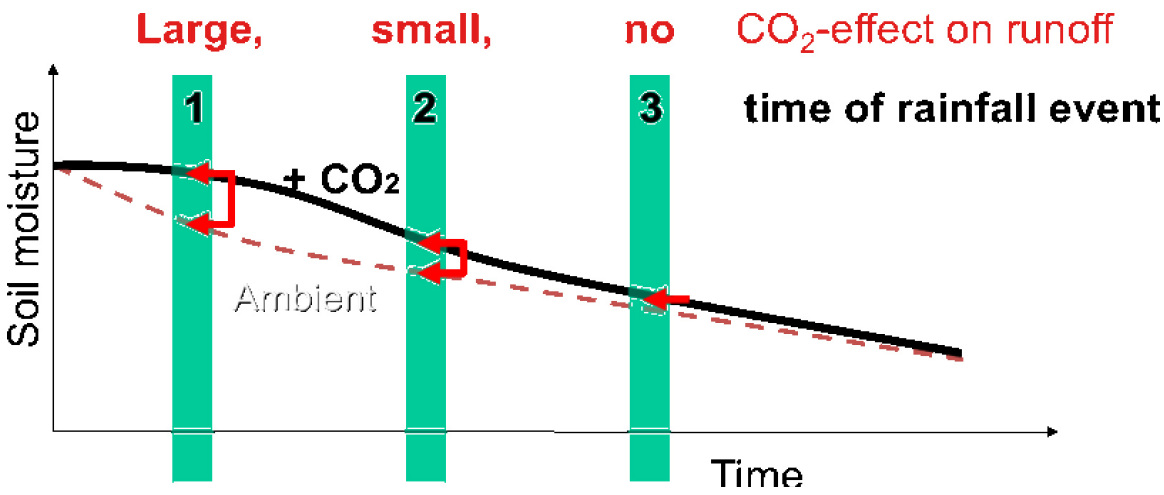

Figure 1. The graphic illustrates the importance of the timing of the rainfall event for the CO_2-effect on runoff.

16.11

Climate change effects on snow melt and discharge of a partly glacierized watershed in central Switzerland

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In the Alps, streamflow regimes and water resource availability critically depend on snow and glacier melt. While the capabilities of numerical models have made significant progress in recent years, it remains challenging to accurately quantify the hydrological response of mountain watersheds to climate warming. Apart from uncertainties that relate to atmospheric forcing data for predictive model runs, dealing with snow and glacier melt, steep terrain, complex micro climatic effects, and unknown groundwater processes poses substantial difficulties to numerically reproduce the hydrological behavior of alpine watersheds.

Here we present results of a comprehensive hydrological study in the drainage area of a hydropower reservoir in central Switzerland. The total basin is partly glacierized (20 %) and spans over 92 km^2 of alpine topography covering elevations between 1800 and 3600 m asl. As is often the case, long-term hydrometeorological data is largely unavailable for the area, apart from reservoir water level measurements. Among other measuring infrastructure, three automatic meteorological stations, continuous discharge measurements at three sites, and two remote camera systems for snow-covered area were installed at the beginning of this study in 2007.

Discharge measurements in feeding streams display strong diurnal fluctuations due to snowmelt in spring and glacier melt later in summer. Three different modeling approaches have been tested to reproduce the measured discharge dynamics: 1) a detailed energy-balance model primarily designed for snow simulations; 2) a temperature-index model developed for glacier mass balance studies; 3) a conceptual runoff model system suitable for mountain hydrology applications. A considerable effort has been put in distributing available meteorological station data to the model grids as forcing data. In particular, the energy-balance model was sensitive to different precipitation distribution methods. With this model, an algorithm accounting for terrain curvature and slope turned out to provide a promising approach.

The recent EU regional climate modeling initiative ENSEMBLES provided up-to-date climate predictions for two periods in mid and late 21st century. These were used to estimate changes in the water supply of the hydropower reservoir in response to expected climate shifts. Our simulations suggest a drastic shortening of the snow covered season by about two months at all elevations by the end of this century. Even at the highest elevations, in many areas the snow cover will no longer persist throughout the summer with evident consequences for the glacier accumulation zones. Thus, peak streamflow in spring from snowmelt will take place earlier, while late-summer streamflow will decrease considerably.

16.12

Low water in a changing climate

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Water resources management requires knowledge about the possible magnitude of runoff in the near and the far future, in order to take consequent measures for adaptation. Providing this knowledge is difficult enough for a more or less stationary system. Facing the ongoing and anticipated changes in climate and land use as well as future socio-economic change renders the task even more challenging.

The interdisciplinary research project CCHydro (Volken 2010) analyses changes in water balance as well as in flood and low water behavior in Switzerland caused by climate change. In the present sub-project we focus on low water. The aim is a projection of low water runoff in the Swiss Midlands for the periods 2021 to 2050 and 2070 to 2099 with an appropriate model. The European heat wave of 2003 showed that low water might be a problem even in Switzerland. Especially in the Swiss Midlands conflicts between water users and ecosystem requirements (like perennial runoff in rivers) are likely during summer months. Therefore low water is investigated here exclusively for catchments in the Swiss Midlands and only for a time window from May to October.

Runoff projections into 2050 or 2099 are a difficult task in general and often based upon weak assumptions. In low water projection, as in all projections, the choice of the model is most important. There are two questions two answer: 1) Which model represents best the entity under research – i.e. low water – in the investigated area and 2) which model is able to represent this entity under climate change. It is crucial to have a process based model in order not to model the errors of the model structure in 2050 or 2099 but the impact of climate change on the water cycle. In addition, low water research in Switzerland suffers from the fact that the occurrence of this runoff extreme is very rare. Model choice, model calibration and model validation are thus difficult. In addition, in the rare periods of low water, the measuring accuracy of water flow is most sensitive for determining low water.

In order to cope with all these problems we decided to find a well-founded modelling approach, based on the analysis of base flow. Starting with the importance of accurate runoff measurements, runoff gauges were selected based on the NQ-stat database (BAFU 2005) quality declaration. 59 catchments all over Switzerland matched these quality requirements (Fig. 1).

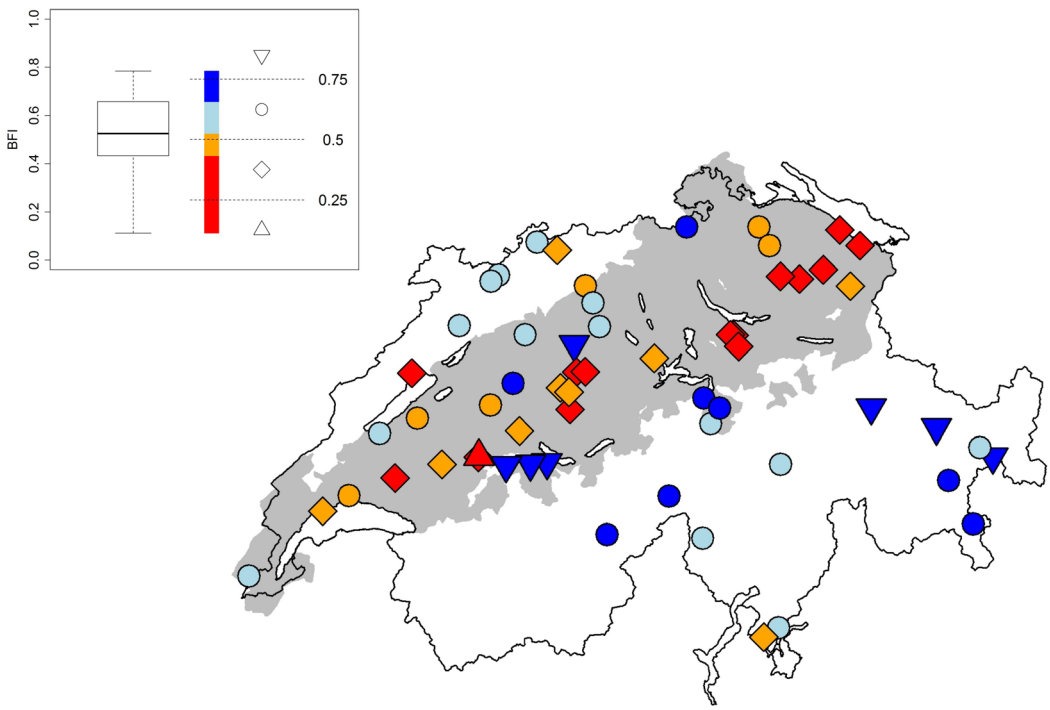

Figure 1. Spatial distribution of the 59 catchments under investigation. Each symbol represents one associated gauge. The shape of the symbol shows an absolute classification of the BFIs, whereas the color shows a relative classification, relative to the totality of obtained BFIs (see inset on top left). The extension of the Swiss Midlands is shaded in grey.

For all of these 59 catchments base flow was determined. Base flow allows an investigation of the complete time series of interest, without any regard to the occurrence of a low water period. The separation of base flow is possible even during high water periods. Base flow is that part of total runoff which originates from delayed sources. It is only this part of runoff which supplies the river with water during periods without rain, and consequently this part of runoff is of interest for our investigation. The base flow index (BFI) is a useful index to describe the low water character of a catchment at a glance. BFI is the ratio between base flow and total discharge over a given time. A BFI of 0.9 thus describes a catchment which generates a stable water supply to the river, whereas a BFI of 0.1 means very little storage of water, quick runoff after a rainfall event and almost no runoff during prolonged periods without rain. Figure 1 shows that low BFIs are almost uniquely located in the Swiss Midlands whereas high BFIs can be found all over Switzerland. By using this BFI we want to empower our model to cope with climate change.

Most models do have their weak points in the groundwater module. So does PREVAH, which we decided to use in an adapted manner for our low water projection. PREVAH is already an established model for average water and high water in Switzerland (Viviroli 2007). With the calibration of its groundwater module against the gained BFI, we prove PREVAH to cope correctly with climate change from the low water point of view.

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16.13

The Holocene sediment record of Lake Cadagno: Overview and initial results from a comprehensive paleoenvironmental study

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Lake Cadagno is a relatively small (840 m long, 420 m wide, 21 m deep) high-alpine lake situated in the Piora valley in the southern part of Switzerland (Ticino) at an altitude of 1921 m. The lake basin was created by glacial erosion. The bedrock of the valley contains dolomite and gypsum, and sulphate-rich water from underwater springs lead to high sulphate concentrations in the anoxic hypolimnion. Microbial sulphate reduction and the subsequent accumulation of sulphide in combination with a strong density gradient result in meromictic conditions of the lake's water body, with a permanent oxicline at about 9 m water depth. High abundances of purple and green sulphur bacteria (*Chromatiaceae* and *Chlorobiaceae*, respectively) at the redox interface in the modern lake, as well as their organic geochemical remnants and signatures in surface sediments at the bottom of the lake were the subject of several research campaigns. Paleoenvironmental studies at lake Cadagno, on the other hand, were restricted to short sediment cores covering the last centuries.
Within the frame work of the SNF funded project "FloodALP" we conducted a seismic survey and recovered a 10.5 m-long composite core from the deepest part of the lake, covering, according to preliminary ^{14}C dating, the last 12000 years. After recovery, the core was sub sampled in high resolution (about every 10 cm) for sedimentological, organic geochemical (lipid biomarker) and molecular (16S rDNA) as well biogeochemcial analyses (pore water constituents, methane, element composition and speciation). In this presentation, we provide a progress report on various collaborative research projects that all aim at reconstructing the paleoenvironmental conditions at Lake Cadagno during the Holocene.

The sediments of Lake Cadagno can be divided into three different types: regular background sediment, flood deposits and intervals of reworked material. The different types of deposits were identified and separated by visual observations (layer thickness, grain size/grading, macro-fossil content, thin sections) or by C and N analysis (%C, %N, C/N ratios, $\delta^{13}C$, $\delta^{15}N$). The detailed analysis of the flood layers indicates that the flood events during the Holocene were most intense between 3500 and 4500 years BP. This evidence towards wetter climatic conditions during the Bronze Age is in agreement with previous work. The sediments sequences of the Little Ice Age cold period (ca. 16th - 19th century) also indicate an elevated reoccurrence of episodic flood events.

We also reconstructed paleo temperatures in the lake Cadagno catchment area using a novel, lipid-based proxy, the MBT/CBT paleothermometer. The MBT/CBT approach is based on the ratio of specific organic compounds derived from fossilised remains (GDGTs) of presumably soil bacteria that are preserved in the lakes sedimentary sequence. Our preliminary results are in very good agreement with estimated values of atmospheric air temperature at Lake Cadagno (~ 0°C, Swiss Meteo), and are consistent with climatological evidence from the sedimentologial investigations. Furthermore, temperature variations recorded by the MBT/CBT paleothermometer match published temperature reconstructions for the last two millennia at nearby locations in timing and magnitude and reflect the extension of the Great Aletsch Glacier during the last 3500 years. Major climate anomalies recorded by the independent proxies and by the MBT/CBT paleothermometer are, for instance, the Medieval Warm Period (ca. 1000 years BP) and a cold spell ~1500 years BP. We could also detect a cold period at about 2500 years ago that correlates in timing with the disappearance of the last lake dwellings in the European Alps. Additional cold periods were observed during the Bronze Age (~3500 and ~4500 years BP) and we found evidence for elevated temperature during the so-called Holocene Climate Optimum (8000 - 5000 years BP).

Ongoing and future work addresses the possible links between climate and environmental/biogeochemical changes within the lake. First bulk C and N isotope results indicate that both the C and N cyles of Lake Lugano have been dynamic during the Holocene. Diagenetic effects on the bulk signals cannot be ruled out completely and will be constrained through compound-specific isotope analyses of shielded organic compounds. An ongoing lipid biomarker/pigment study aims at reconstructing the population dynamics of anoxigenic, phototrophic bacteria and the reconstruction of past redeox conditions in the lake. Biomarker data will be integrated with sedimentary data on fossil DNA. Preliminary results indicate that the recent microbial community is not a unique phenomenon of the modern lake and its recent past, as we were able to detect both purple and green sulphur bacteria in several sediment horizons, indicating extended intervals of water column anoxia at Lake Cadagno during the Holocene.

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16.14

Approching water stress in the Alps – Water management options in the Crans-Montana-Sierre region, Valais, (MontanAqua): Measuring network and influence of land use and land use changes on water balance.

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The main objective of the current transdisciplinary project is to develop strategies moving towards a more sustainable water resources management in the Crans-Montana-Sierre region (Valais), together with actors involved. The study region is situated in the driest part of Switzerland and has been subject to dynamic economic, tourism and urban development during the last decades. The proposed research on more sustainable water management options will evaluate co-ordination and adaptation of water demand to water availability under changing biophysical and socioeconomic conditions.

For the detailed assessment of the available water resources in the study area, today and in the future, two distinct sources of water must be considered: (1) the in-situ water resources resulting from the natural water balance; (2) water which is transferred from different sources (e.g. glaciers, reservoirs) through the system by natural flows (rivers, subsurface flows) and by artificial channels within the irrigation scheme.

The study area is highly differentiated across the altitudinal range, and does not cover a classical hydrological basin as the water flows frequently across natural hydrographic boundaries, what is a big challenge from a hydrological point of view. Assessment of present hydrological conditions by observation will be the basis for establishing a detailed hydrological model for the entire study region. In-depth assessment of the present and future availability of water will allow identifying

areas with water surplus and deficits respectively. Results will be strongly related to the issue of evaluating the impact of different land use practices.

The observations are made through a dense measuring network (Fig. 1) , which was installed in spring and summer 2010. The network will stay on place for the duration of the MontanAqua project. Weather stations, rain gauges and totalisators were installed at different altitudinal ranges to assess the input of water in the system. The output is measured by discharge stations which are installed on the main rivers of the area. We also use several weather stations and discharge stations installed and used by other organization or by private offices. To complete the measuring network a hillside lysimeter is built in the study area in an extensive meadow on the lower area. This will precisely measure the evapotranspiration of an unirrigated typical vegetation type of the area. Soil humidity, with tensiometer will also be investigated in the main land use types.

The diversity in land use and land cover is another main characteristic of the study area: the lowest slopes are dominated by vineyards, above which an area with intensive as well as extensive farming (intensive meadow and extensive pasture) and expanding dry forests is situated. In the medium altitudes, tourist resorts and tourist activities are predominant. The highest part of the area is a typical alpine landscape with alpine meadows used for cattle grazing at summer time. The land use practices in the different altitudinal zones of the study area have different water requirements and water use efficiency that will be assessed by the tensiometers and the hillside lysimeter (Fig. 2, next page). Identification of optimal agricultural land management practices (vineyard, meadow, pasture, forest and alpine meadow) will be conducted, especially in the context of irrigation, and their influence on the water budget today and under climate change. A model such as SWAP used in Netherland or in India could be used (Singh et al. 2006a,b, Van Dam et al. 2008) Additionally, we will assess new land use options, which are better adapted to climate variability and extremes. Such investigations have been made in various parts of the world and have been partly capitalized on by the global WOCAT program (http://www.wocat.net/en.html). For the Swiss mountain region, such studies are missing in large measure.

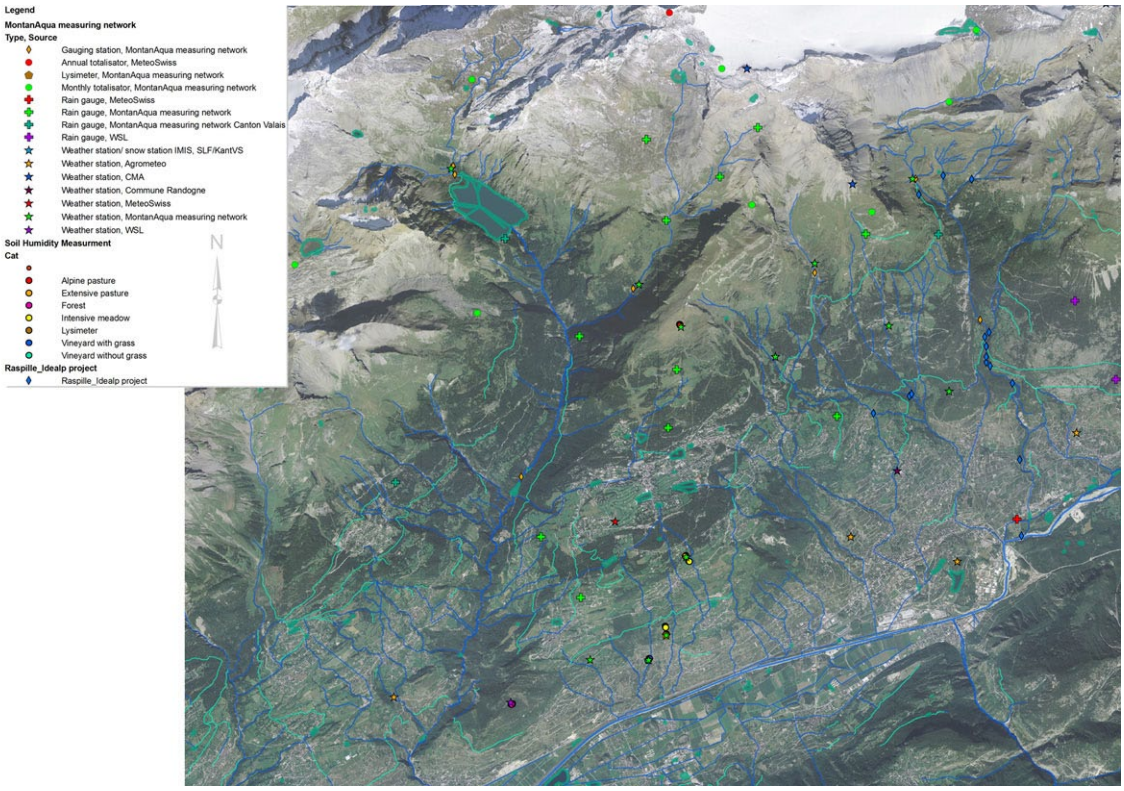

Figure 1. Measuring network of the MontanAqua project.

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Figure 2. Hillside Lysimeter with exter tensiometer and weather station, Lens-Chermignon, August 2010.

16.15

Freshwater biodiversity under climate warming pressure: identifying the winners and losers in temperate small waterbodies

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Climate warming is affecting the composition of communities all around the world, resulting in the expansion or contraction of the geographical range of species, and leading to colonisation (winners) and extinction (losers) events in ecosystems. It is crucial for the conservation of biodiversity to identify the potential winners and losers involved in such changes.

We focus here on small standing waterbodies in Switzerland and on five taxonomic groups: vascular plants, snails, beetles, dragonflies and amphibians. We first investigated the sensitivity of each species to climate warming through their thermal preferences, using altitudinal and latitudinal distribution as a surrogate for temperature. We then investigated the resilience of species to perturbations through five ecological and biogeographical criteria applicable to the perturbation "warming": dispersal ability, degree of habitat specialisation, geographical extent in the study area, future trend in geographical extent, and future trend of habitat availability for species.

When considering only the thermal preferences of species, the proportion of potential losers ranged from 0% to 33% of the regional species pool according to the taxonomic groups. The set of potential winners was much larger; it comprised from 53% to 63% of the regional species pool for dragonflies and amphibians. The resilience criteria combined into a multimetric index added complementary information on the sensitivity of species to warming and enabled to classify all species along a gradient of extinction risk. This threat linked to warming appeared to be different from the threat identified by the present Red Lists and should therefore be used as a complementary label by the managers in charge of species conservation.

16.16

Stable nitrogen isotopes in chitinous remains: Exploration of a new palaeoenvironmental proxy for past freshwater environments

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In ecological studies stable nitrogen isotope ratios ($\delta^{15}N$) are used to trace food web structure, based on the observation that $\delta^{15}N$ of organisms is on average 3.4 ±1.1‰ higher than that of their food source. Additionally, $\delta^{15}N$ can be used to identify changes in the source of nitrogen in an ecosystem. However, $\delta^{15}N$ has rarely been measured in fossil remains preserved in lake sediments even though this would potentially allow the reconstruction of past food web structure and changes in the nitrogen source of lakes.

We show in an experimental setup with larvae of the chironomid midge Chironomus riparius that $\delta^{15}N$ of both soft tissue and fossilizing head capsules faithfully reflect the $\delta^{15}N$ of their food source and that there is a constant offset between the $\delta^{15}N$ of soft tissue and the $\delta^{15}N$ of fossilizing structures. This is in agreement with findings by Perga (2010), who found that $\delta^{15}N$ of cladoceran exoskeletons reflects the values measured in soft body tissue, albeit with a consistent offset.

A field study showed that there is considerable variability in $\delta^{15}N$ of cladocerans and chironomids in Lake De Waay (the Netherlands). This variability was apparent within taxa, between taxa and between seasons. Moreover, analysis of samples

of subfossil remains showed spatial (i.e. within lake) variability in $\delta^{15}N$. Repeated sampling of fossils from core-tops retreived at the same location resulted in consistent results, however.

A downcore record of $\delta^{15}N$ in fossil cladoceran and chironomid remains was produced and compared to trends in bulk sediment organic matter $\delta^{15}N$ and trends in nitrogen deposition on the Netherlands. The results suggest that bulk sediment organic matter $\delta^{15}N$ increases and decreases as lake productivity rises and declines due to changes in anthropogenic nitrogen deposition on the Netherlands. More importantly, the $\delta^{15}N$ of fossil remains of cladocerans and chironomids show similar trends, yet with an amplitude two to three times larger than bulk sediment organic matter $\delta^{15}N$.

The results of this study show that $\delta^{15}N$ of chitinous remains of chironomids and cladocerans provides a good approximation of $\delta^{15}N$ of tissues of once living organisms. In Lake De Waay, and possibly in similar lakes, $\delta^{15}N$ measured on these remains can be used to reconstruct past changes in nitrogen source of the lake system. Our results suggest that $\delta^{15}N$ of chitinous remains of aquatic invertebrates is more sensitive to changes in nitrogen source $\delta^{15}N$ than $\delta^{15}N$ measured on bulk sediment organic matter. This study may lead to the development of $\delta^{15}N$ in chitinous remains as a new indicator for past trophic conditions in lakes.

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16.17

Towards uncertainty reduction of low flow modeling using $\delta^{18}O$ as additional information

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Droughts and low flow have severe consequences for both natural and social systems including impacts on ecosystems, agriculture, water supply and energy production. An early recognition of critical drought conditions is favorable to society and economy and thus essential for drought risk management. A common tool to estimate hydrological responses is the use of hydrological models. Often conceptual rainfall runoff models are applied, because they are able to capture the dominant catchment dynamics while remaining parsimonious and computationally efficient. However, modeling brings uncertainty along, which should be quantified. The identification of the sources of uncertainty is crucial for reducing uncertainty through changes in structure, parameterization and error models, which account for uncertainty in the forcing and output data. Little work has been done particularly regarding the sources of uncertainty in the modeling of low flow situations. We modeled low flow in a small-scale research catchment in Switzerland (Rietholzbach catchment, www.iac.ethz.ch/groups/seneviratne/research/rietholzbach) using multiple conceptual hydrological models. The various sources of uncertainty were estimated using the Bayesian total error analysis (BATEA) framework (Kavetski et al., 2006). Within this framework the modeler can transparently incorporate, test, and refine existing understanding of all sources of data uncertainty in a specific application, including both rainfall and stream flow measurement uncertainties. The hydrological models differed in the structures known to be important to capture low flow processes i.e. percolation as well as soil and groundwater storages in modeling. The models are extended to enable mass transport and thus allow modeling the isotopic signal for all model components. After optimizing also for the simulation of the isotopic signal ($\delta^{18}O$) the uncertainty is re-analyzed.

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