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Transport, Energy and Communications DETEC

Federal Office for the Environment FOEN
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31.05.2016

Research Concept (updated):

Climate Change and its consequences on Hydrology in Switzerland Hydro – CH2018, a NCCS Focus Area

Reference: P215-0939

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1 Background

The National Centre for Climate Services (NCCS, www.nccs.ch) was founded in November 2015 and entrusted with the responsibility of strengthening intersectoral cooperation in climate services in accordance with the Adaptation to Climate Change in Switzerland action plan adopted by the Federal Council [7]. Its specific duties include the development of scientifically-based data and information for the purposes of improving common, practical bases as well as the promotion of knowledge sharing between researchers/scientists and users (e.g. authorities responsible for climate change adaptation, associations, organisations, environmental agencies and private bodies). The NCCS is the Confederation's response to a recommendation from the Global Framework for Climate Services (GFCS), which was launched by the World Meteorological Organization (WMO) at the third World Climate Conference in Geneva in 2009.

The FOEN's Hydrology Division is in charge of the " Climate Change and its consequences on Hydrology Hydro-CH2018" focus area at the NCCS. The objective of the Hydro - CH 2018 focus area is to provide the required hydrological bases for climate change adaptation measures (i.e. based on the new CH2018 climate scenarios) and to establish a platform for knowledge sharing between researchers and users in the area of hydrology and climate change. This climate service should enable authorities, the economy and society to reduce climate-related risks, recognise and take advantage of opportunities, and reduce costs.

In-depth knowledge of the hydrologic cycle and its development are of central importance in the context of adaptation to climate change in Switzerland, as many other sectors besides water management are concerned (e.g. agriculture, energy management, tourism). That is why it is important for decision-makers to have assessments of future developments in the individual components of the hydrologic cycle (quantity and quality parameters) at their disposal. The FOEN's CCHydro project or the National Research Programme 61 (NRP 61), which serve as bases for the Hydro - CH2018 focus area, were already providing important information of this kind. In addition to process knowledge about the hydrologic cycle, however, ongoing (long-term) hydrologic cycle monitoring must be ensured and adapted by continuously integrating new methods and findings.

2 Anticipated Results

The objective of the "Hydro - CH2018" focus area is to develop and provide the hydrological bases for climate change adaptation measures for a broad range of users from authorities and economic actors to private stakeholders. This includes:

- **further development and conservation** of current hydrologic (long-term) surface water and groundwater monitoring by continuously reviewing and adapting monitoring networks to changing challenges.
- **regular analyses** of hydrologic data, particularly data from "Hydrologischen Untersuchungsgebieten (HUG)" to identify and ensure early recognition of changes resulting from climate change. This also includes providing the decision-makers concerned with relevant information about medium and long-term developments in water management components (such as water temperature, hydrological extreme events or sediment transport).

- **a better understanding of the hydrological process** and efforts to fill knowledge gaps through targeted research projects. This includes the provision of the knowledge base for the measures formulated in the Federal Council's climate adaptation action plan for Switzerland [7] as well as in the Federal Council's response to the Postulat Walter [17].
- an **update of hydrological scenarios** based on the new CH2018 climate scenarios.
- support for the **establishment of a knowledge sharing platforms** (networking events) between scientists/researchers and users and the contribution of input to other NCCS focus areas (e.g. extreme events)

3 Relevant Literature

The following completed or ongoing research programmes/projects are considered important groundwork and need to be efficiently incorporated:

[1] Effects of Climate Change on Water Resources and Watercourses (CCHydro). FOEN 2011
[2] Water Resources in Switzerland: Supply and Use – Today and Tomorrow (NRP61). SNF 2014.
[3] The ASG Rhine project of the CHR concerning percentages of the snow and glacier melt in Rhine runoff (Synthesisreport to be soon available)
[4] Ongoing research projects and projects with research aspects of the FOEN's Hydrology Division. More specifically: low water and groundwater, heavy precipitation and floods, rain on snow, water temperature
[5] Other ongoing FOEN projects, particularly in the Water and Hazard Prevention Divisions *(concrete examples follow)*
[6] CH2014-Impacts (2014), Toward Quantitative Scenarios of Climate Change Impacts in Switzerland, published by OCCR, FOEN, MeteoSwiss, C2SM, Agroscope, and ProClim, Bern, Switzerland
[7] Adaptation to Climate Change in Switzerland: Action Plan 2014–2019. Second Part of the Federal Council's Strategy of 9 April 2014 (in German)
[10] Foresight Report Hydrological Research in Switzerland, 2013
[11] Analyse der Nutzerbedürfnisse zu nationalen Klimaszenarien (in German)
[12] 7. Symposium Anpassung an den Klimawandel - "Klimaszenarien: von der Forschung zur Anwendung" (2015), Workshop Themenkreis Wasser
[14] Bases for the Water Supply 2025 (in German)
[15] Effects of Climate Change on Hydropower (in German). Synthesis report 2011.
[16] Adaptation to Climate Change in Switzerland: Screening Research and Implementation Activities and Current Monitoring Systems (in German). Final report 2015.
[17] Bundesratsbericht zum Postulat Walter, 2012 (in German)
[18] Expertenberichte 1-3 Projekt Wasserressourcenplanung und Bewirtschaftung, 2016 (in German)
[19] Auswirkungen von Hitze und Trockenheit auf die Gewässer 2003, 2004 (in German)
[20] Abschätzung des Bewässerungsbedarfs in der Schweizer Landwirtschaft, 2010 (in German)

In the first phase of the project, a comprehensive "state of the art" report will be prepared to better define the focus areas of research and identify the already existing knowledge.

4 Planned Work

1. Synthesis Report

The starting point and end product of the Hydro-CH2018 focus area is a comprehensive (rolling) synthesis report based on the most current research findings and ongoing and planned research programmes/projects in Switzerland. It will be

updated on a regular basis and start by providing an overview of the state of the art in the field of hydrology and climate change in Switzerland that specifically takes into account the projects listed under “Relevant Literature”. Then, it will incorporate the findings of ongoing Hydro CH-2018 projects. This report, in combination with expert workshops, should provide the basis for identifying and addressing existing research gaps. While several research gaps have already been identified by previous projects and can now be directly addressed, other knowledge gaps might only be identified as the project is being carried out or the synthesis report is being drafted.

2. Coordination and Knowledge Sharing

Effective coordination within the FOEN (primarily the Water Division and the Hazard Prevention Division), with other federal offices, and with other NCCS focus areas and close cooperation with all relevant research institutions is a prerequisite for reaching the above formulated objective. Effective coordination and communication between all those involved (NCCS, Federal administration, Swiss universities, private organisations) are necessary so that redundancies and overlapping between the Hydro - CH 2018 focus area, ongoing research activities, and other NCCS focus areas can be minimised as much as possible and knowledge gaps can be addressed in a targeted manner. Therefore, coordination and knowledge sharing play a key role in the Hydro - CH 2018 focus area.

The first coordination event is a Kick-off workshop with all involved institutions in May 2016, where the concept for the Hydro - CH2018 focus area will be presented and discussed. Within this framework, the research priorities should be identified.
Furthermore, the Hydrology Division will organise more information sharing meetings and workshops in various forms:

- small workshops with specific technical themes (intermittently, as needed)
- a coordination meeting for the Hydro – CH2018 focus area with all those involved to report progress in the project and discuss the next steps (once per year)
- larger information event(s) at the end of the project to present the findings
- information about the status of work at other regularly occurring events such as climate adaptation workshops (held annually by the FOEN/Proclim) or NCCS events

3. Closing Research Gaps

To achieve the objective of closing current knowledge gaps in the area of hydrology, specific research programmes addressing identified research priorities will be initiated. Based on research gaps identified in previous projects and feedback from experts/stakeholders, the following priority topics were defined for the Hydrological Bases focus area at the NCCS:

I. Natural and Artificial Water Storage – Effects on the Future Water Balance

Relevance:

By temporarily removing water from the hydrological cycle (in the short or long term) and returning it at a later point in time, natural and artificial water storages play a key role in water resources management in Switzerland. For instance, snow cover and glaciers retain water and thus shift runoff from winter to spring or summer.

Switzerland's many natural and artificial lakes can also store large quantities of water and strongly influence the discharge regime of underlying bodies of water. Groundwater stores a similar quantity of water to lakes and represents a major, yet still poorly understood reservoir. In-depth knowledge of the anticipated changes in seasonal water storage as a result of climate change (e.g. in groundwater, snow and ice, in the soil but also in regulated and unregulated lakes and reservoirs.) is a prerequisite for successful water resources management. Pressure is growing on Switzerland to implement climate adaptation measures in the area of natural and artificial lake management. In fact, the type of regulation applicable to several major sub-alpine lakes is currently at the centre of discussions with Italy and France. For that reason, it is extremely important to clarify the hydrological and ecological aspects of this type of lake and reservoir management and its interdependency to the other natural water storages. That is why this area of research should be given priority, particularly in connection with measures 24-26 formulated in the Swiss adaptation strategy adopted by the Federal Council [7].

Objectives and potential research topics:

- comprehensive assessment of natural and artificial storages in Switzerland and their potential changes in the context of climate change
- mutual influence of natural and artificial storages now and in the future
- assessment of the potential contribution of water retention in natural and artificial storages to the management of water quantity problems [w4][7]
- Swiss lake and reservoir management in the international context (creation of the knowledge base) [w6][7]
- sustainable use of groundwater depending on changes in volume and accessibility (What is sustainable usability? What type of use is not wasteful?)
- changes in the snow line as well as the snow and glacier volume (and the consequent lake formation) and the resulting changes in seasonal reservoir capacities, effects on discharge regimes
- evaluation of new reservoir capacities (e.g. construction of reservoir structures for irrigation/drinking water)
- potential for active management and increased temporary use of natural and artificial reservoirs

Identified research priorities:

- **Interaction** between different storages (ice, snow, groundwater, surface water, soil moisture)
- **Water management** of reservoirs, lakes and groundwater, soil moisture (seasonal forecasting)
- **Water demand scenarios**
- **Other influences: Socio-economic, revitalisation, land use changes**
- **Feedback to climate**

II. Water Temperature and Water Quality in Surface and Groundwater

Relevance:

Water temperature is a key parameter for chemical, biological and physical processes and greatly influences water quality, water ecology and the potential use of bodies of water. In the future, the average air temperature will continue to rise and lead directly to markedly higher water temperatures across Switzerland [1, 2, 7]. Since surface water temperature is particularly sensitive to changes in climate, it is an excellent indicator. For example, higher water temperatures linked to climate change causes cooling water to lose its cooling capacity, threatens fish stocks and allows invasive species to spread, which endangers ecology as a result. Rising water temperatures in lakes stabilise stratification, thereby promoting a shortage of oxygen or causing the increased formation of toxic secondary metabolites through cyanobacteria. For bodies of water at high altitudes, rising temperatures are indirectly coupled with runoff, which is influenced essentially by glacier and snowmelt. With decreased snow cover and glacier ice in the future, the water temperatures of surface waters in regions at higher altitudes will rise disproportionately [6].

Due to the highly interconnected functionality of water temperature, comprehensive process knowledge is of central importance. Preliminary and important groundwork has already been carried out in [1], which provides potential projections of changes in water temperature in watercourses, as well as in the FOEN project that investigates spatial and temporal changes in water temperature in Swiss watercourses ("Untersuchung der räumlichen und zeitlichen Veränderungen der Wassertemperatur in Schweizer Fliessgewässern"). In addition, studies on climatic and anthropogenic stresses in lakes and their corresponding effects on ecological systems are being conducted in the FOEN process aimed at improving Switzerland's water management ("Optimierung Wasserwirtschaft Schweiz") with the "Use of Surface Waters for Heating and Cooling" project in connection with the project focused on the temperature of bodies of water and climate change ("Gewässertemperatur und Klimawandel").

The knowledge base developed up until now is still insufficient and incomplete, which is why more efforts are required to derive projections and scenario analyses and incorporate them in operational forecasts. Although these cannot be prepared at the national level right now, they are crucial to the measures formulated [w7, w8, w6, e6, b1, b3] in [7].

Objectives and potential research topics:

- investigation of the validity of the linear regression model for various regions/ altitudes/ water levels/ channel geometries
- temperature development in glaciated catchment areas
- quantification of temperature change in watercourses in consideration of 1) projected air temperature change 2) increased regime changes (e.g. through runoff from reservoirs, snow melt or increasing low water events) 3) surface water/groundwater interaction
- measurement, documentation and evaluation of water temperatures in standing bodies of water on a national level as concerns 1) long/short-term influence by climate changes and thermal uses 2) scenarios regarding effects (e.g. on currents and stratifications in lakes) 3) influence on groundwater

- target-oriented process modelling 1) which includes the relevant processes, 2) selection of process areas, 3) quantitative information about the interaction and impacts of processes, 4) identification and coordination of common EPFL/EAWAG interfaces (continuation of the EPFL project for watercourses and new projects with EAWAG for lakes)
- clarification of the relevance of temperature-induced releases of climate gases CO_2/CH_4 in connection with the storage potential of surface waters
- influence of anthropogenic discharges, particularly in low water situations (wastewater treatment installations, power plants, industry, …)
- Water temperatures in small and medium river waters, as many temperature sensitive species are encountered in these
- Effects of increased water temperatures on aquatic organisms (only well known for a few fish species so far)
- Influence of a higher percentage of riverine wood vegetation on the water temperatures of small rivers

Identified research priorities:

- **Interaction** of groundwater with surface water (renaturing, uncertainty in quantitative statements)
- Influence of **CC on water quality in lakes** less understood than influence on rivers (especially temperature)
- **Extremes and seasonal changes in water temperatures** as key aspects for ecology
- Fill knowledge gaps to establish **clever montoring** strategy

III. Extreme Events (Flood and Low Flow Events)

Relevance:

An increasing frequency of extreme hydrological events accompanied by a constant rise in potential damage is a huge risk for society: While local water supply shortages and usage conflicts can occur due to increased and prolonged low water flows (e.g. 2003, 2011, 2015), floods cause millions of CHF in damage (e.g. 2000, 2005). It is known that climate change will continue to impact the mean values and the distribution of climatic variables and therefore also the frequency and seasonal occurrences of extreme (hydrological) events. Detailed event analyses (e.g. 2005 flood event analysis) and repeated evaluations of previously implemented protection measures contribute substantially to making flood protection in Switzerland more sophisticated and effective in the future. Only through a better understanding of the underlying processes (e.g. extreme rainfall events, runoff formation, sediment transport) information about future developments can be acquired to provide a basis for appropriate adaptation measures. However, the downscaling method applied in the CH2011 climate scenarios, i.e. the delta change method, makes it only partially possible to analyse and extrapolate such extremes to the future. There is still a great deal of uncertainty surrounding the hydrological models, which is why calculations may very well have to be supported by observation-based scenarios for the time being (until the CH2018 climate scenarios are available).

Objectives and potential research topics:

1. *As concerns low flow events:*

- changes in low water flows and periods of drought (periods without precipitation), building on the findings of [1], [2], and the FOEN's ongoing "Impacts of Climate Change on Groundwater and Low Water in Switzerland" project.
- regional, river section-specific study of the behaviour of Q_{347} values and other low-flow indices (depending on inflows, ex/infiltration, colmation)
- characterisation of recovery after dry spells, influence of different dry spell sequences, varying sensitivity of catchment areas (in connection with the response of Po. Walter? Summer/Fall 2015 analysis? Findings of groundwater and low water projects)
- Further developments in the field of aridity indices: i.e. Precipitation – Evapotranspiration – budget as raster layer for Switzerland (www.droughts.ch)
- Mean monthly and yearly runoffs and runoff types to be provided as raster layers for Switzerland

2. *As concerns floods:*

- changes in heavy precipitation as a precursor of floods and therefore flood situations (variables, location, time), based on the FOEN's ongoing extreme precipitation and floods project and in coordination with the Extreme Events focus area
- update of calculation methods/models (measurement) for flood assessments (e.g. HQ100), for example, based on a "precipitation generator", which generates high-resolution temporal and plausible extreme precipitation patterns that can be used to model the time series of flows. This would allow a simulation of the various possible future time series in consideration of local weather characteristics.
- changes in sediment inputs and bedload transport caused by the thawing of permafrost ground and changes in heavy precipitation and flood discharges.

Identified research priorities:

- Socio-economic changes vs. Climate change
- **Definition of hydrological extreme events** (soil moisture, groundwater, snow), consequences must also be considered
- **Process chains** in hydrological extremes
- Priorities for Hydro-CH2018: other extremes than floods, no good strategies for «other» extremes
- **Adaptation to floods relatively good** compared to other extremes

IV. Hydrological Evaluation of CH2018 Climate Scenarios

Relevance:

To obtain reliable information about how Switzerland's climate will develop in the future, regularly updated, detailed climate scenarios are required on both the regional and local levels. Such climate scenarios are the central basis for the Confederation's climate change adaptation strategy. They are also required by a wide range of different

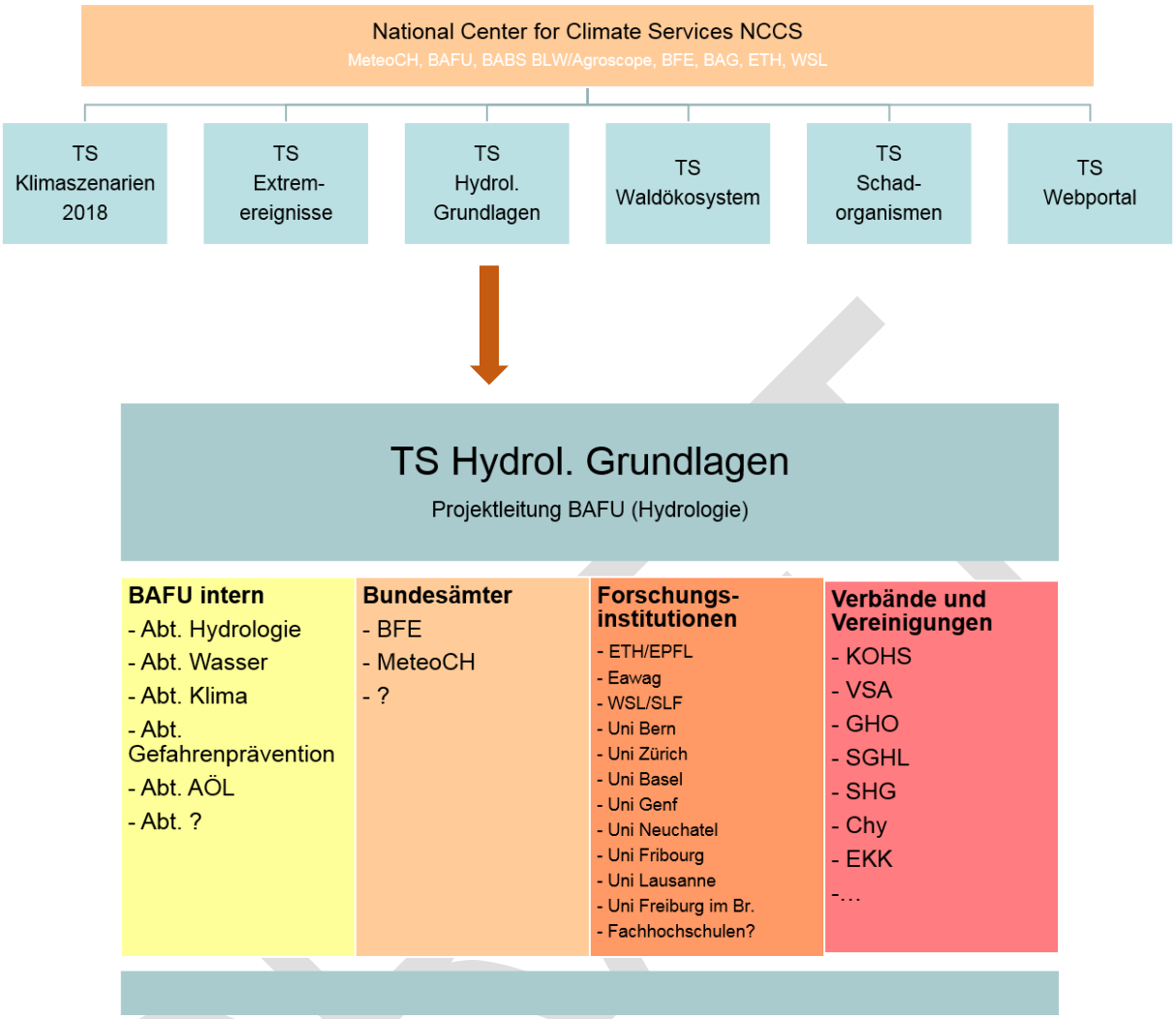
sectors and in the hydrology and research community they serve as a basis for adaptation strategies or further studies. For that reason, new climate scenarios based on the latest regional climate model simulations and using current scientific methods are being developed as part of the “CH2018” focus area at the NCCS. The goal is to align these scenarios as best as possible with the needs of users, which is why market research analyses have already been conducted [11]. The requirements of the hydrological community were consolidated in a specific workshop as part of the “Climate Change Adaptation” symposium in 2015 [7]. As a result, the focus of the CH2018 scenarios are changes in climate extreme and seasonal mean values, application-orientated climate indicators, as well as the provision of daily weather time series that reflect the future climate.

Objectives and potential research topics:

- The calculation of new hydrological scenarios must be evaluated based on the downscaling method used for the CH2018 scenarios and other calculated parameters (in addition to precipitation and temperature). Two scenarios are conceivable in that respect:

    1. The CH2018 climate scenarios provide markedly different results for extreme events (e.g. based on better downscaling methods or improvements in climate models) than the CH2011 climate scenarios. In this case, a new calculation of hydrological scenarios would be important and contribute new quantitative and qualitative knowledge, particularly in the area of flood and low water events.
    2. The extreme and mean values of the CH2018 climate scenarios hardly differ from the CH2011 scenarios. A new calculation of hydrological scenarios based on CH2018 would merely cause a change in the decimal place and would not provide a great deal of new knowledge. In this case, a new calculation would not be initiated.

5 Project Organization Chart



6 Timetable (General)

Task	2016				2017				2018				2019			
	Q1	Q2	Q3	Q4	*Q1*	Q2	Q3	Q4	*Q1*	Q2	Q3	Q4	*Q1*	Q2	Q3	Q4
Project initiation																
Project management/ Coordination																
Concept finalisation																
Call for research project proposals																
Survey of state-of-the-art/synergies																
Evaluation of research projects																
Duration of research projects																
Interim reports/ Meetings																

Synthesis report/input AP 2014-2019																
Hydrological scenarios																
Project completion																

7 Publication of the Findings

- Publication of the findings, data and activities on the NCCS Web portal
- Scientific publications in specialised journals by the commissioned research institutes
- Contribution of information to the activity report or the climate change adaptation strategy of the Federal Council (2019)
- Publication of a synthesis report, e.g. in an issue of “Environmental Studies” by the Federal Office for the Environment for a wider, interested public
- Other possible products: “Climate Fact Sheets”, “Climate Signal Maps”, hydrological outlook, etc.
- Final meeting in the press briefing (public relations)