ACQWA

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A summary for policymakers

ACQWA: Assessing Climate impacts on the Quantity and quality of WAter
A large integrating project under EU Framework Programme 7 (FP7), coordinated by the University of Geneva, Switzerland (2008-2013)

UNIVERSITÉ DE GENÈVE

SEVENTH FRAMEWORK PROGRAMME

ACQWA at a glance

Title: Assessing climate impacts on the quantiy and quality of water (ACQWA)

Instrument: Large integrating project, FP7

Total Cost: 8,563,566 Euros

EC Contribution: 6,493,573 Euros

Duration: 60 months

Start Date: 01.10.2008

Consortium: 30 partners from 10 countries

Project Coordinator: Prof. Martin Beniston, University of Geneva

Project Director: Dr. Markus Stoffel, University of Geneva

Project Web Site: http://www.acqwa.ch/

Key Words: Climate change, cryosphere, hydrology, socio-economic impacts, extreme events, governance, adaptation strategies

ACQWA project summary

The challenge

Future shifts in temperature and precipitation patterns, and changes in the behaviour of snow and ice in many mountain regions will change the quantity, seasonality, and possibly also the quality of water originating in mountains and uplands. As a result, changing water availability will affect both upland and populated lowland areas. Economic sectors such as agriculture, tourism or hydropower may enter into rivalries if water is no longer available in sufficient quantities or at the right time of the year. The challenge is thus to estimate as accurately as possible future changes in order to prepare the way for appropriate adaptation strategies and improved water governance.

Project Objectives

The project seeks to assess the vulnerability of water resources in mountain regions such as the European Alps, the Central Chilean Andes, and the mountains of Central Asia (Kyrgyzstan) where declining snow and ice are likely to strongly affect hydrological regimes in a warmer climate. Model results are then used to quantify the environmental, economic and social impacts of changing water resources in order to assess how robust current water governance strategies are and what adaptations may be needed in order to alleviate the most negative impacts of climate change on water resources and water use.

Methodology

Current generations of state-of-the-art models are being applied to various interacting elements of the climate system, that include regional atmospheric processes in complex terrain, snow and ice, vegetation, and hydrology in order to project shifts in water regimes in a warmer climate in diverse mountain regions such as the Alps, the Central Andes of Chile, and the mountains of Central Asia (Kyrgyzstan). Observations, targeted models, and methodologies from the social sciences are applied to the impacts analyses on sectors such as tourism, agriculture and hydropower which could be strongly impacted upon by changing water regimes. The results from these different approaches then serve to suggest recommendations for adaptation and updated water governance strategies.

Exploration of specific science and policy themes

- An integrated modelling approach to enable accurate projections of changes in the seasonality and quantity of runoff in the river basins under scrutiny in the ACQWA project
- The identification of key economic impacts on a number of sectors, including the possible compounded effect of changing frequencies and intensities of extreme events
- An assessment of the possible rivalries between economic actors that will be faced with changing water resources
- A portfolio of possible water governance strategies to alleviate future problems of water allocation and use, of relevance to future revisions of the EU Water Framework Directive

Project Partners	
University of Geneva, Switzerland (Coordination)	CNR-ISAC, Torino, Italy,
Forschungsanstalt Reckenholz-Taenikon, Switzerland	Fondazione Montagna Sicura, Valle d'Aosta
ARPA Piemonte, Italy	ICTP, Trieste, Italy
ARPA Valle d'Aosta, Italy	National Academy of Science, Bishkek, Kyrgyzstan
Universität für Bodenkultur, Vienna, Austria	CEA, Gif-sur-Yvette, France
Universidad de la Serena, La Serena, Chile	Monterosastar SRL, Italy
Centro de Estudios Cientificos, Valdivia, Chile	Max Planck Gesellschaft, Hamburg, Germany
Instituto Torcuato di Tella, Buenos Aires, Argentina	Ente Parco Nazionale Gran Paradiso, Italy,
Università degli Studi di l'Aquila, Italy	Politecnico di Milano, Italy,
CNRS, France (3 entities: Grenoble (2) + Paris-Bellevue)	Universität Bern, Switzerland
CSIC, Zaragoza, Spain	The University of Birmingham, UK
Compagnia Valdostana delle Acque SPA, Italy	Universität Graz, Austria, Andreas GOBIET
ENEL Produzione SPA, Roma, Italy	University of Dundee, UK
ETH-Zürich (3 entities), Switzerland	IHEID: Graduate Inst. of Int'l and Development Studies, Geneva, Switzerland
Centre d'Etudes de la Neige, Grenoble, France	Ricerca sul Sisema Energetico (RSE), Milan, Italy

Climate and hydrological impacts in the ACQWA case-study regions

Swiss Rhone Catchment

- Summer and spring drying; wetter winters; temperature increases by 2050 (roughly 0.9°C).
- Earlier snow-melt (5-10 days); increased melt in April and May
- Significant reduction in glacier melt contribution expected by 2050 (70%) decrease in summer run-off (25%: Rhone; 50%: high elevation glaciered catchments).
- Lower frequency of debris flows; increase of event magnitude due to stronger precipitation and larger sediment sources.
- Seasonal output likely to be modified with decreasing flows in low-demand periods (Jul/Aug) and increasing flows in high demand periods (Apr/May). Total annual decrease in ice-fed reservoirs is likely to negatively affect production.
- Increase in consumption due to crop evapotranspiration, potential water shortages for crop growth are likely. More pressure on small rivers with less supply from glaciers.

Italian Po Catchment

- From 2001-2010 to 2041-2050: Increase of temperature ranges between 15.2% and 17.5%, and variation of mean annual precipitation ranges from 1.-9.6% (mainly Jan-Mar).
- Accelerated melting periods; increase in evapotranspiration (summer) counteracts the influence of the larger amounts of summer precipitation on river discharge.
- Decrease of flow discharge is estimated to be more than 50% of the seasonal average for a large portion of the drainage network.
- Shifts in seasonality will affect the rules governing dam management to take into account increased availability of water in the earlier months of the year and a longer summer period with much less water left for runoff.

Aconcagua Basin, Chile

- Warmer winters; decreasing precipitation, changes in snowpack, changes in the timing of snow and glacier melt and generally increasing dry periods.
- Shifts in seasonality and decreases in glacier melt are particularly significant in the Andean region due to the high dependence on glacier and snow melt run off for water availability during the dry summer months.
- Decreasing amounts of precipitation during summer are likely to be exacerbated by a decrease of glacial melt-water releases in the long-term due to reduced glacier volume impacting summer irrigation of water intensive crops (e.g. avocado, table grapes).
- Water transfers across the basin for water resources supply have already been undertaken.
- Reduced run-off in summer is likely to affect the management of run of the river hydropower plants.

Amu Darya, Syr Darya, Kyrgyzstan

- Decrease in summer precipitation (4-7%); increase in winter precipitation (4 to 8%) by 2050. Temperature increases are projected (+2.6-4.4°C) for all seasons.
- More extreme events: summers droughts and winter/spring floods.
- Loss of glacier volume eventually leading to decrease of glacier-fed summer runoff.
- Earlier and more intense snowmelt; decrease in snow cover duration.
- More importance placed on the buffering effect of glaciers to release additional water during dry summers in compensation for rain shortfalls for domestic, industrial and irrigation use. A tipping point is likely to be reached when glacier contributions diminish.
- Irrigation demand (cotton, wheat) accounts for 90% of water demand in the region, is vulnerable to drought and increased variability from climate change impacts.
- Total hydropower potential of the rivers may decrease by up to 14%

Main policy implications

Comprehensive, sustainable, transformational adaptation

ACQWA has developed climate information for a set of mountain regions downscaled to temporal and spatial scales that are intended to be more useful to the challenges decision makers face. Climate change impacts in a number of basins dominated by snow and ice show that water managers and users will need to adapt to change in the quantity and timing of water resources. This is not only relevant to local and regional scales, but also to communities and economic sectors downstream who are reliant on a range of goods from mountain regions and their resources (e.g. electricity, water, water storage in the form of ice and snow).

A certain level of uncertainty has always existed in water resources planning due to climate variability. Climate change represents an increase in uncertainty and the speed and magnitude of change. Water policy and management frameworks therefore must manage and cope with both existing and increasing levels of uncertainty from climate variability and climate change impacts. **While principles in the management, conservation and adaptation of water resources and ecosystems abound, there remains a lack of clear policy guidance on practical governance mechanisms and actionable measures, *especially in the context of mountain areas.***

Synergies or conflicts across different sectoral policies are particularly relevant in mountain areas, where fragile ecosystems provide valuable economic services such as energy for hydropower, water towers and natural storage systems of water, tourism uses, etc. Existing tensions across sectors, governance scales and actor groups are likely to be further heightened by impacts from climate change, underlining the need for not only integrative but also adaptive water resources governance and management. In the highly sensitive and complex environments of mountain areas, known as 'sentinel sites' in their early responses to climate change, adaptation options tend to be limited in comparison to lowland areas.

ACQWA policy work therefore focused on:

- ***identifying underlying water governance challenges in the mountain case regions:***
- ***assessing adaptive capacity of these regions;***
- ***identifying practicable governance mechanisms and actionable measures for the operationalization of adaptive and integrative water resources management and governance principles, specifically for the alpine context.***

Climate change in the mountain regions studied are leading to modifications in quantity and timing of water resources that have potentially significant ramifications for water governance and management. Water managers will need to adapt to potential increases in runoff in late winter and autumn and potential decreases in spring and late summer. Snow melt is likely to take place earlier, with increased melt in spring, but less change will be noticed at lower than higher elevations. **One of the strongest effects is the significant reduction in glacier melt contribution expected by the middle of the century, and a constriction of the period where glacier melt is significant** that will have repercussions for the management of hydropower reservoirs. At present, glaciers and snow pack provide a valuable buffer of additional water during dry summers. While increased glacial runoff from melting glaciers will at first lead to surface runoff surpluses, **continued reductions in glacier volume will eventually result in a decrease of summer runoff**. In some of the ACQWA case areas, this phenomenon is already occurring.

Enabling framework for adaptability to climate change in an Alpine context

Adaptation policy needs to be sensitive to the challenges of spatial (local-national) and temporal scales (short – long term; climate variability – climate change). This is particularly important in mountain regions where highland ecosystems provide goods and services to lowland areas, economic imbalances persist across highland-lowland scales, multiple sectors compete for water resources at different seasonal points, and the impacts of climate change are likely to be acute. Water governance and management will therefore need to minimize trade-offs across different sectoral requirements and not degrade **resilience** at other scales, **avoiding lock-ins** (rights, infrastructure, land-use planning, economic, water requirements, energy mixes) with **expensive reversal costs**.

- Water governance (systems and rules in place that affect the use, protection, delivery and development of water resources) and to be both adaptive and flexible in developing and setting rules that regulate hydro-power, water rights allocations, urban growth and spatial planning for both current climate variability and climate change.
- Water managers need to be able to make decisions under uncertainty, in their application of rules and the operationalization of policy for the practical aspects of water allocation and protection, as well as protection from and during extremes.
- An adaptable water management and governance regime must not only manage current baseline uncertainty levels of climate variability (e.g., stochasticity of precipitation) but also the more unpredictable forms of un-
- certainty arising from climate change (e.g. shifts in seasonality as glaciers melt)
- Actionable measures that operationalize these principles are required in order to alleviate underlying tensions that are likely to be exacerbated by climate change impacts. Technical adaptation should prioritize no-regret, reversible,

flexible and iterative actions, that take a long term and ecosystem based approach (rather than purely grey infrastructure based) and integrate both adaptation and mitigation requirements.

- Infrastructure will need to be robust to flows of a larger range than prior climate conditions, but which in itself will be highly uncertain. Infrastructure design should therefore account for natural climate variability and change through stochastic approaches that examine multiple possible trajectories.

Multi-goal infrastructure should also be developed for redundancy, dynamism, uncertainty or enhanced benefit across the social and ecological system.

Identifying and alleviating exacerbation points

Governance and management challenges: common lessons drawn across the ACQWA basins

- **Fit:** The scale at which water is managed (user/management) can block longer term catchment scale planning and smoothing over shifts in seasonality creating critical local situations.
- **Sectoral focus:** The lack of integrative water and adaptation planning at catchment or basin levels. Policy goals may be integrative, but divisive in implementation/management.
- **Lock-in:** The legacy of technical and grey infrastructure and spatial planning (concreting of river reaches, removal of river bed, building zones in floodplains, commitment to single economic sectors, focus on specific species conservation, etc.) leads to a decrease in resilience as baseline conditions change; Fixed and long term of concessions or rights that do not account for impacts on hydropower production and timings.
- **Rules and incentives:** Lack of formal rules on certain uses; New, un-regulated uses (e.g. increasing use of snowmaking; Lack of demand management integrated into spatial planning; Lack of formal mechanisms to manage competition across catchment areas.

Developing adaptive capacity to respond to challenges of uncertainty and climate change impacts

Water governance will need to not only overcome the challenges laid out above, but do so in a way as to include climate variability and prepare for climate change, by balancing the requirements for structure and predictability at higher governance scales with the flexibility at lower scales to react at lower governance scales.

From adaptive principles to governance mechanisms in policy and legislation

<u>POLICY MAKERS AND MANAGERS MUST NOT ONLY BETTER MANAGE PREVIOUS LEVELS OF HYDRO-CLIMATIC VARIABILITY</u> **but also a wider envelope of variability and uncertainty associated with climate change**. Table 1 presents a means of framing the adequacy of available governance mechanisms to cope with these scales of uncertainty.

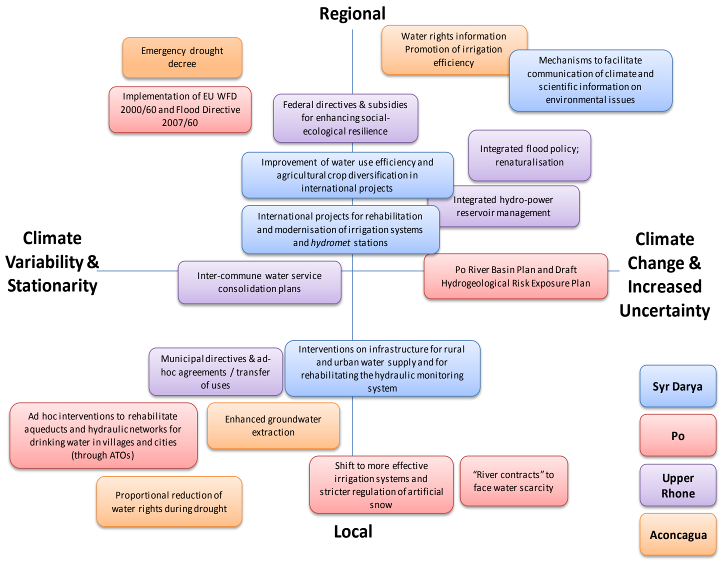

***Figure 1**: Adaptive capacity in relation to scales of issues*

	Stationarity with predictable uncertainty	Broader uncertainty with reduced predictability	Irreversibility and Regime shifts
Review Periods	Assessment of outcomes.	Inclusion of climate data.	Incorporate climate scenarios.
Varied rights	Equitably match demand to supply.	Vary use rights in advance of expected changes.	Manage larger shifts in timing or volume of availability.
Time limited licencing/permits	VARIABILITY MORE IMPORTANT IN SHORT TERM.	MUST BE SUBJECT TO VARIABILITY.	Maximum duration of the permit will influence the usefulness.
Entitlements as share of overall resource	Annual allocation based on expected resource availability	Integrate climate projections for review and revision of long term planning framework.	Reduce the proportion of the resource that is available for use.
Water rights trading	Distributing rights in areas or times of limited availability.	CHALLENGES OF SPECULATION AND PRIORITISATION OF DIFFERENT USES.	LESS EFFECTIVE AT ADDRESSING VARIABILITY.
Administrative requirements	For basin management, appropriate user involvement, use cadastres.	Use cadastres at multiple scales, reinforce compliance and integrate emerging science.	<u>STRONGER REQUIREMENTS FOR</u> integration of emerging science and impact scenarios.
Qualitative and quantitative standards	Guide short-term permit variability requirements and abstraction controls.	Variability critical, but in context of combined approach.	Reactive variability and integration of new conditions required.
Locally appropriate standards	Appropriate for guiding short-term use right variability.	<u>SECONDARY BASIN/LOCAL SPECIFIC LEGISLATION USEFUL, NOT IMPERATIVE.</u>	Primary legislation may be more relevant for larger variability.
Monitoring standards	<u>VITAL TO ENSURE NETWORK FUNCTIONING, AVAILABILITY AND EXCHANGE.</u>	Fundamental to the integration of climate data.	Fundamental to the integration of climate scenarios and data.

***Table 1:** Possible pathways to alleviate risks associated with climate impacts*

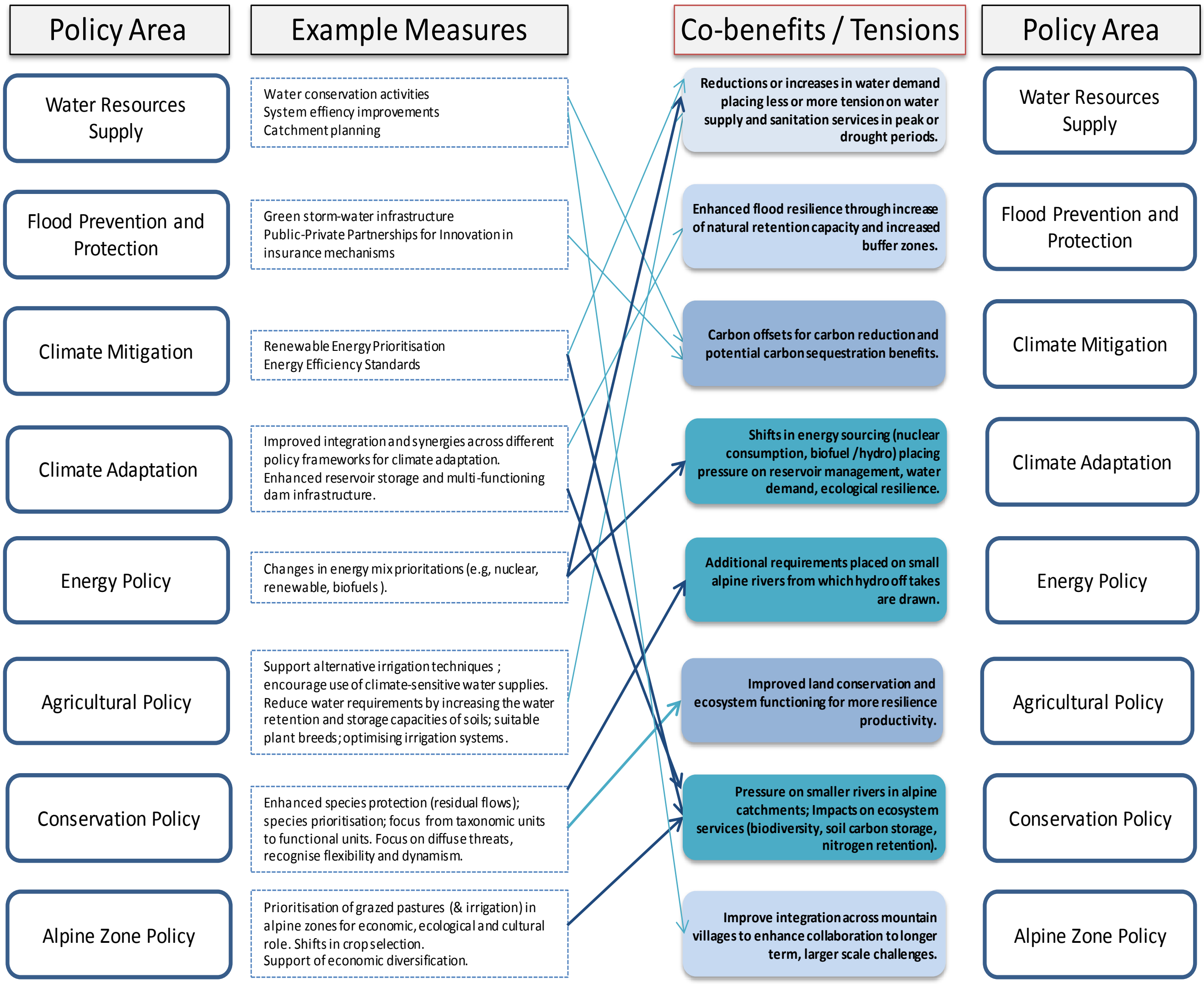

Figure 2: *Actions and policies to optimize decision-making in the face of climate impacts*

Many challenges in developing adaptive capacity relate to challenges of vertical and horizontal integration, where flows of knowledge and data, rules and plans, formal and informal institutions, policy goals and local or regional laws, plans and priorities are not aligned across governance scales or natural boundaries to either fulfill management goals or prepare for emerging challenges. This is particularly important in mountain regions, where multiple sectors (hydropower, tourism, agriculture, domestic supply, mining or other industries) operate across a catchment, but geographical and political boundaries are often not aligned.

Policies may be vertically integrated through frameworks such as strategic or environmental impact assessments, or horizontally integrated by formal and informal institutions (e.g., river basin management organizations, user groups).

Figure 2 provides some examples of how specific actions and policies would optimize multiple benefits across conservation – adaptation – mitigation policy spheres.

The Rhone Glacier, Switzerland

ACQWA Project: Summary of main research findings

Methods and Models

- Ensembles data (ensembles-eu.org: highest standard regional climate models) were used for climate simulations at a spatial resolution of 25 km for European domain, using IPCC A1B emissions scenario.
- Improved application of regional climate simulations (grid spacing 25 km, effective resolution 100 km) in order to better model hydrological processes in complex alpine terrains (grid-scales of a few 100 metres) by correcting errors, focusing on downscaling, and creating high resolution data for greater Alpine area until 2050.
- 2^{o}C warming projected by 2050, most prominent above 1500m in autumn.
- Precipitation may increase in winter and decrease in spring and summer.
- Decrease in snow depth is projected to be most visible in winter and spring.
- Extremes: major differences in RCMs than GCMs simulations and highly uncertain. Higher frequency of precipitation event occurrences projected as well as more separate wet periods within events, with shorter durations but higher intensity.

Projected changes: regional climate

- Stronger warming is expected along the Alpine ridge, especially in summer, with stronger warming in the Western Alps (+1.7°C in winter; 1.9°C in summer)
- Warming is more certain for winter and spring than summer. Choice of global climate model to generate the results has the largest effect on total uncertainty.
- High spatial variability is likely for precipitation with increases in the north of the Alps in spring, summer and autumn, and decreases in southern and western parts.
- Precipitation results have a high level of uncertainty, with regional climate models contributing more than the global models to total uncertainty.

Projected changes: snow and ice

- Alpine snow cover will decline due to temperature increases (more rain/less snow), particularly at mid-latitude locations between 1000-2000m.
- Results from a novel numerical model (includes water flow in a sub-glacial drainage network) projects that climate change will affect the stability of certain alpine glaciers.
- State of the art, continuous mass balance models project a high variability of progressive glacier retreat for 2001-2050 and a related ice volume reduction for 6 contrasting alpine glaciers.
- Debris-free glaciers are projected to have a faster negative mass balance in comparison to those covered by a thick layer of debris. Higher spring and summer melting occurs in 2031-2050.
- Glacier retreat may slow where glaciers become confined to high elevations if accumulated precipitation in winter is high; ice melt contribution to runoff in glaciarized catchments accordingly is projected to gradually disappear.
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Projected changes: hydrology

- The effects of climate change on the hydrological cycle appear less evident in the higher part of the alpine region (e.g. for the high part of the Rhone) than for lower elevations (e.g., the Padan Plain, Po).
- RCMs projected impacts of climate change on flow duration curves of mountain tributaries for the Po River exhibit a general decrease of discharge for high durations (low flows) and an increase in discharge for low durations (high flows). Results from GCMs are more variable. Decrease of flow discharge is estimated to be more than 50% of the seasonal average for a large portion of the drainage network.
- Downscaling from 25km to 3km resolution has significant impacts on the change in the annual hydrological cycle due to the detailed spatial description required for snow coverage, precipitation distribution and temperature in alpine regions.
- In the Rhone, internal (stochastic) climate variability is a fundamental source of uncertainty, larger than the projected climate change signal while changes in the natural hydrological regime imposed by the existing hydraulic infrastructure are larger than climate change signals expected by 2050.
- Climate change impacts on stream flow are elevation dependant, with a severe reduction at high elevations due to the missing contribution of water from ice melt and a dampened effect downstream: decrease of water availability in summer and in increase of discharge in winter.
- While local changes may be of some relevance, it is unlikely that major changes in total runoff for the entire upper Rhone basin will occur in the decades up to 2050.

Extreme events

- Investigations suggest a remarkable intensification of extreme precipitation events at the end of the 21st century in Switzerland; increase in intensity and frequency in the upper and southern Rhone valley have already been observed since 1990.
- Cut-off low systems are significant contributors (20% - 95%) to large scale heavy precipitation events in the most exposed northern and eastern parts of the Alps; current models underestimate the precipitation in regions where an essential part of the precipitation stems from cut-off lows.
- Global seasonal precipitation extremes for the 21st century (using 8 new high- resolution GCM simulations) show that in the mid and high latitudes of both hemispheres, a significant intensification of extremes is evident in all seasons by the end of the century.

- Despite uncertainties, recent developments at high-elevation sites clearly show that the sensitivity of mountain and hillslope systems to climate change is likely to be acute, and that events beyond historical experience will continue to occur as climate change progresses.
- Glacier down-wasting and the related formation of ice-marginal lakes, ice avalanches and debuttressing is leading to rockfalls and slope instability at progressively higher elevations; volume, but not frequency, of debris flows is likely to increase further.

Climate-driven hazards

- Despite uncertainties, recent developments at high-elevation sites clearly show that the sensitivity of mountain and hill-slope systems to climate change is likely to be acute
- Events of magnitudes beyond historical evidence will continue to occur as climate change progresses.
- Glacier downwasting and the related formation of ice-marginal lakes, ice avalanches and debuttressing is leading to rockfalls and slope instability at progressively higher elevations
- The volume, but not necessarily the frequency of debris flows are likely to increase further.

Multiple Impacts

- A warming between 1-2ºC and a decrease of precipitation between 5-20% is projected for the Spanish Pyrenees (A1B scenario, 2021-2050).
- An increase of warm events during winter months is also expected in the region.
- A rise in temperature of 1ºC implies a 20% decrease in snow accumulation at 2000 m (higher sensitivity at lower altitudes than upper elevations) for the region.
- Increased vegetation in the Upper Aragón river basin could potentially decrease annual stream flow in the by 16%, mainly in early spring, and autumn.
- Controlling land cover may be a mitigation strategy to minimise the probable reduction of available water resources.
- Projected climate change could decrease annual stream flow by 13.8%, mainly in late spring and summer.
- Combined effects of forest regeneration and climate change may reduce annual stream flow by 29.6% leading to difficulties in meeting current water demand based on present and planned regulation capacity in headwater areas.

Impacts on hydropower

- Variability in glacier retreat patterns (size, aspect, shape, debris cover, etc.) has consequences for the management of hydropower plants and dams, which depend primarily on snow- and ice-melt.
- Reduction in surface water flows and seasonal shifts in water availability (more availability of water in the earlier months of the year and a longer summer period with lower run-off) will impact hydropower. Climate change also indirectly affects electricity load because energy consumption varies with air temperature.
- Technological, economic and behavioural changes in the electricity system are, however, expected to exert a stronger impact on hydropower.
- In the Po region, greater variability in river flows and decrease in snow fall will affect the filling of hydropower reservoirs (e.g., decreasing ability to use all the storage capacity) and increase the inter-annual variability of electricity production.
- Storage-hydropower plants are a more flexible technology with modifiable production periods, whose revenues are less vulnerable to shifts in seasonality than run-of-river.
- While more even contribution from runoff might advantage reservoir management, a decrease in total annual runoff expected for reservoirs fed by ice melt is likely to negatively affect production.

Impacts on agriculture

- Until 2050 major agro-climatic risks will likely be generated by high temperatures rather than by increased drought (negative effects on both crop and livestock production).
- With increasing temperatures, water consumption through crop evapotranspiration increases is likely to lead to additional irrigation demands to maintain optimal yields (e.g. +10% in July at Visp across a range of climate scenarios up to 2049).
- High demand for water for irrigation will put additional pressure on small rivers in catchments with little or no water supply from glaciers, while larger water sources in valley may not be subject to the same extent of variability.
- In drier areas with low summer precipitation (e.g. valley floor and the south-facing slopes), potential water shortages for crop growth would be likely, requiring more irrigation to maintain optimal crop yields (max. +35%).
- In extremely dry years irrigation requirement could potentially exceed surface water availability in smaller catchments with a nival runoff regime, where water is drawn through small irrigation channels for grassland irrigation.
- In the upper Rhone valley, improved water management should include both regulations regarding the allocation of water to different users of the same source, installation and management of reservoirs, and technical measures to improve the efficiency of irrigation by avoiding losses of distribution systems, evaporative losses, and excessive runoff due to over-application of water.
- Shifts in intensification of grassland use may have negative consequences for other ecosystem services such as biodiversity, soil carbon storage, and nitrogen retention

Impacts on aquatic ecosystems

- Increased temperature, seasonal precipitation shifts, reduced ice cover and ice melt are likely to have significant implications for aquatic biodiversity: increased abundance of larger predator species, increased primary and secondary productivity, increased local diversity, decreased regional diversity.

- Successful application of a water source approach in a changing cryosphere across multiple river basins highlights its potential for use in future alpine conservation planning.
- Cases from the Pyrenees (sentinel site) and the Swiss Alps highlight that although climate signals are broadly similar, the predicted hydrology – habitat – ecology responses are varied and are a function of cryospheric river flow buffering potential (i.e., glacier size).
- A shift is proposed to move provisions and policy guidance on conservation approaches from focusing on taxonomic units to functional units. New baselines should be set based on ecosystem functioning rather than taxonomic diversity.
- To better align principles and provisions in conservation and water resources legislation and policy with the projected impacts of climate change on freshwater ecosystems, three key shifts are proposed: (i) move from focusing on direct and point source impacts to diffuse threats; (ii) recognise flexibility and dynamism in the system, rather than aiming to control static ecosystems; (iii) improve integration and synergies across different policy frameworks that impact conservation.

Impacts on mountain forests

- Sensitivity of mountain forest ecosystem services (carbon storage, runoff, timber production, diversity, and protection from natural hazards) to a 2 °C warmer world depends heavily on the current climatic conditions of a region, the strong elevation gradients within a region, and the specific ecosystem services in question.
- At low and intermediate elevations large negative impacts will occur in dryer-warmer regions, where relatively small climatic shifts result in negative drought-related impacts on forest ecosystem services.
- At higher elevations and in regions that are initially cool-wet, simulations suggest that forest ecosystems will be relatively resistant to a 2° temperature rise.
- Some services such as protection against rock-fall and avalanches are sensitive to 2°C global climate change, but other services such as carbon storage are reasonably resistant. A 2 °C increase of global mean temperature therefore cannot be seen as a universally “safe” boundary for the maintenance of mountain forest ecosystem services.
- Analyses provide pivotal information for ecosystem management by pinpointing regions and ecosystem services that are most likely to be particularly sensitive, thus allowing ecosystem managers to concentrate their efforts and to spend limited financial resources in a most effective way.

Impacts on tourism

- A more local approach to winter tourism exposure to climate change in the Rhone catchment (comparing across average winters, a snow-poor winter with average economic conditions and a snow-rich winter at the beginning of the current economic crisis) reveals high disparities between mountain resorts and a higher vulnerability than regional approaches have suggested.
- The hotel sector is less exposed to a snow-poor winter than the cable-car companies, but faces difficulties in some areas when longer trends and socio-economic factors are taken into account.
- There is a real need to increase cooperation among and within resorts and touristic regions, enhance co-ordination of water uses (e.g. , between hydro and cable-car companies), to improve the promotion of the Canton in general, to improve the ability to consider alternatives to skiing during warmer winters (notably in more vulnerable regions), and to improve current regulation on artificial snow-making.

Lessons learnt from non-European regions

- These have illustrated the challenges of climate change impacts in basins characterised by less robust institutions and lower levels of climate data.
- Governance assessments were conducted and technical tools developed (to advance the estimation of total volume of water equivalent storage in the glaciers and of climate change impacts in general).
- In the drier climates of central Andres (Aconcagua and Cuyo basin) and central Asian (Syr Darya basin), glaciers and snow pack play vital role in natural storage of melt water for release for irrigation purposes in the drier summer periods.
- In all three case areas, the combination of decreasing amounts of precipitation during summer are likely to be exacerbated by a decrease of glacial melt-water releases in the long-term due to reduced glacier volume.
- Comparisons of water governance assessment across non-European and European basins underline the importance of enhancing institutional and actor trust in order to adapt to increased periods of summer drought in particular.
- Often, current reactive adaptations (e.g., increased [illegal and legal] groundwater exploitation, water transfers, water withholding) degrade the resilience of the ecological system as well as the trust required to build longer term, more proactive strategies to address climate impacts.
- Improved monitoring of ecosystem and water rights, accessible and available data integrated into decision making, integration of multiple knowledge sources, reinforcing and integrating user groups already in place, and more accessible, affordable and expedient conflict resolution mechanisms are recommended to enhance the adaptive capacity of these systems.

Challenges for future research

Large integrating projects generally represent a step forward in furthering our understanding of various complex processes and interactions between environmental, economic, social, and technological systems. The ACQWA project is no exception to this rule, and the five years of research has indeed enabled a number of issues to be refined and clarified, but has also identified problem areas that would need to be addressed in future investigations of this nature.

In January 2011, the ACQWA project organized a workshop in Riederalp, Switzerland, where over 25 EU projects focusing on water resources and water management were represented. Institutional and financial obstacles to data access for use in modeling exercises were identified, and gaps in scientific knowledge that contribute to uncertainty were highlighted. A working paper was subsequently published in 2012 in *Environmental Science and Policy*[1] to report on the main conclusions of this crucial meeting. The discussions summarized in the paper have identified a number of sectors where these gaps often represent barriers to successful research outcomes, and suggested ways and means of alleviating some of these difficulties. A major issue that has been raised is that of data for research purposes. Policies aimed at ensuring free and unrestricted access to data, especially those generated by the numerous research projects that focus on issues of water availability, quality and management have been recommended. Implementation of the recommendations formulated in the *Environmental Science and Policy* paper may help pave the way for a more rapid and efficient production of research results that are of importance for policy guidance at the local, national and supra-national (EU) levels.

There is a clear need for a **more integrated and comprehensive approach to water use and management.** In particular, beyond the conventional water basin management perspective, there is a **need to consider other socio-economic factors and the manner in which water policies interact with, or are affected by, other policies at the local, national, and supra-national levels**. As an example, **it is unclear whether current EU water policies are consistent with energy, agriculture, and other industrial policies**.

The problems highlighted during the Riederalp meeting and summarized in the cited paper are also related to the **inconsistencies between physical and socio-economic data and models**. For example, figures related to water use may not be available at the temporal and spatial detail required by hydrologic models. Hydrological information is often based on basins whereas economic (and social) data is aggregated into administration regions. Thus, economic and physical data are often incompatible, because they are collected by different entities for different purposes. **Future research should thus address the development of compatible data sets and the conversion between different data formats**, as well as the development of toolboxes for up-scaling, downscaling and bias correcting data. Furthermore, the use of water in production processes is often not mediated by the market. **The use of economic flexibility mechanisms in the allocation of water resources is quite rare**, despite their potential in improving the efficiency of water resources allocation**.** **More research and policy initiatives in this direction are thus necessary.**

Finally, many scientists working in large integrated projects highlight a large **gap between Science and Policy**. This is certainly at least partly due to problems of **communicating in an appropriate manner the key research results that would be of use to policy-relevant strategies**. Awareness of this problem is increasing within the EC and other policy institutions, and hopefully this new momentum will be sustained over time so that conclusions from EU and other water-relevant projects will be widely incorporated into future policies at the local, national, and supra-national levels. Ultimately, the **implementation of guidelines, maybe even an EU Directive, on the good governance of data** (sharing) could be envisaged as a possible framework, providing advice and general rules on data formats and standards, data storage after project completion or the general terms of access.

1: **Beniston, M.**, Stoffel, M., Harding, R., Kernan, M., Ludwig, R., Moors, E., Samuels, P., Tockner, K., 2012: Obstacles to data access for research related to climate and water: implications for science and EU policy-making. *Environmental Science and Policy*, 17, 41-48.

El Juncal, Chile, headwaters of the Aconcagua River

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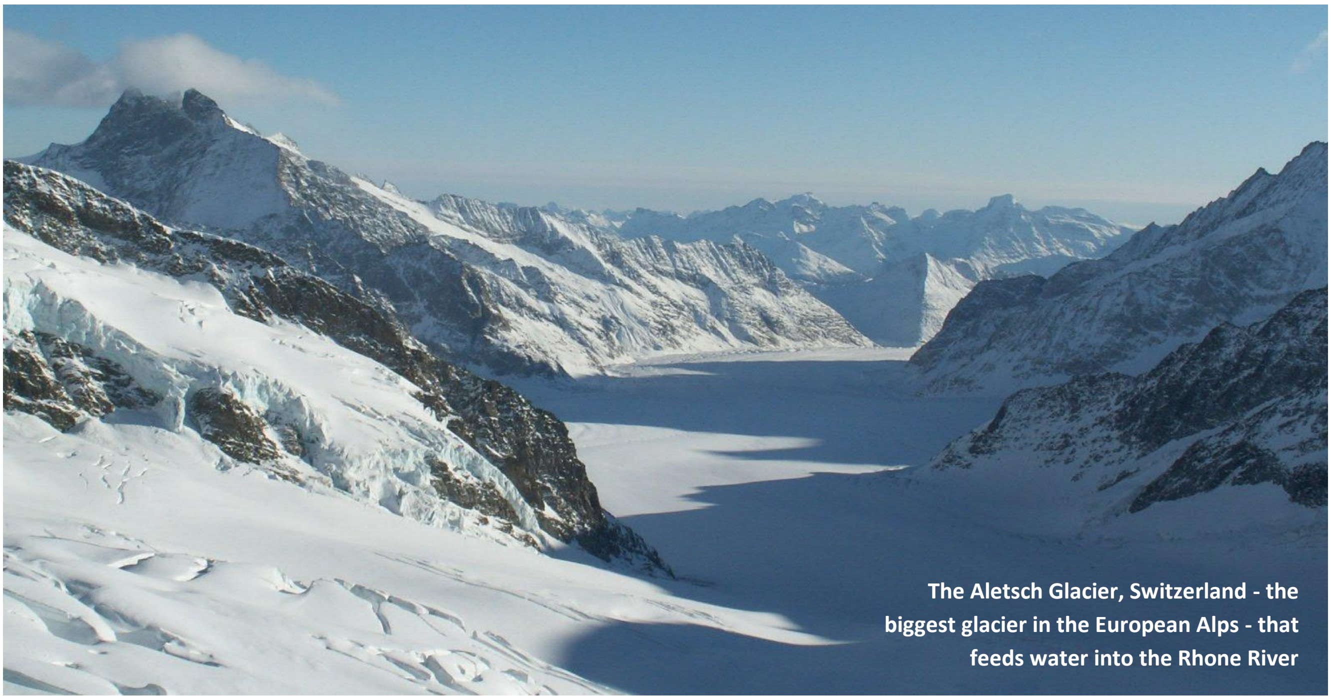

The Aletsch Glacier, Switzerland - the biggest glacier in the European Alps - that feeds water into the Rhone River