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Source: Mountain Research and Development, 33(3) : 248-259

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-12-00106.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

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Adaptive Capacity of Water Governance: Cases From the Alps and the Andes

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The Alps and the Andes are both considered water towers in their respective continents and are thus significant not only for their own water needs but also for those of lowland regions farther downstream. As climate change impacts on the hydrology of mountain regions are increasingly observed, attention is turning to the adaptive capacity of the water governance regimes in mountain communities. This paper explores the adaptive capacity of two contrasting water governance regimes in the Swiss Alps and the Chilean Andes. It assesses adaptive capacity by analyzing a set of governance-related adaptive capacity indicators in the context of recent extreme events, which serve as proxies for future climate change. Across these highly contrasted governance contexts, analysis reveals both similar and distinct institutional challenges for developing and mobilizing adaptive capacity in relation to climatic uncertainty and change. It also identifies emergent tensions related to temporal and spatial scales. Conclusions point to the need to focus on challenges relating to trust, integration of hydroclimatic information, and flexibility and iterativity of rules and plans across governance scales to better manage the exacerbating impacts of both climate variability and climate change.

Keywords: *Climate change impacts; water governance; adaptive capacity; Alps; Andes.*

Peer-reviewed: *May 2013* ***Accepted:*** *June 2013*

Introduction

The Alps and the Andes—commonly considered "water towers" for their respective continents—will both be significantly and disproportionately affected by climate change (Beniston et al 2003; Nogués-Bravoa et al 2007). Climate change impacts on glacier retreat, precipitation patterns, snow lines, and associated changes in runoff regimes are already being observed in Alpine and Andean regions, and model projections suggest a continuation, if not heightening, of current trends (Pellicciotti et al 2007; Viviroli et al 2011). These impacts take on global relevance, because mountain regions are a major watershed resource for more than half of the world's population for hydroelectricity, drinking supplies, or other water resources (Grêt-Regamey et al 2012). With rising global water consumption (Molden et al 2007), sustainable and adaptable water management in these regions becomes increasingly critical.

As impacts of climate change are increasingly observed, climate resilient adaptation strategies are called for that reduce vulnerability and potentially increase the adaptive capacity of both social and ecological systems (Matthews et al 2011). Governance-related adaptive processes have thus become a key component for maneuvering toward more sustainable water resources management (Brooks et al 2005; Pahl-Wostl 2007). Effective water governance and management is seen as being at the heart of present and future water challenges and is considered crucial for building adaptive capacity to climate change (Brooks et al 2005; Nelson et al 2007): the ability to prepare for and respond to stresses from climate variability and climatic change stress (Engle 2011).

This paper intends to present new comparative empirical evidence on the adaptive capacity of 2 contrasting water governance regimes in the Swiss Alps and the Chilean Andes. The highly contrasting governance contexts reveal both similar and distinct challenges for institutions and actors to manage and respond to hydroclimatic events. The article aims to provide more insights into the challenges relating to temporal and spatial scales that governance regimes must navigate when they aim not only to manage hydroclimatic stresses and uncertainty but also to enable longer-term resilience to climate change impacts.

Background: adaptive capacity

Adaptive capacity is the ability of a system to adjust to changing internal demands and external circumstances (Carpenter and Brock 2008). Within a social system, adaptive capacity is defined as the capacity of actors (collectively or individually), to respond to, create, and shape variability and change in the state of the system (Adger et al 2005). Building and mobilizing adaptive capacity requires actors not only to be able to adapt

http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00106.1

TABLE 1 Overview of initial identification of governance and institutional determinants of adaptive capacity.

Determinants	Related criteria
Knowledge	Right to information; communication and public perception; access to scientific and environmental information; exchange of data and information; integration of scientific expertise; quality of scientific information; use of traditional and local knowledge (Olsson et al 2004; Folke et al 2005; Ostrom 2007)
Networks	Access to participation; selection of nonstate actors; level of influence; type of participation and stage in the political process; social networks and professional networks; willingness to cooperate (Berkes and Folke 2001; Folke et al 2005)
Levels of decision making	Ecologically based units of decision making; institutional arrangements (Berkes and Folke 2001; Pahl-Wostl, Craps, et al 2007; Huitema et al 2009)
Integration	Geographic integration; sectoral integration; governance-scale integration (Pahl-Wostl, Kabat, et al 2007; Engle et al 2011)
Flexibility–predictability	Consistency in rule of law; predictability of legal provisions; iterativity in laws, plans, and institutions to deal with uncertainty (Keeney and McDaniels 2001; Pahl-Wostl et al 2007b; Iza and Stein 2009; Herrfahrdt-Pähle 2010)
Resources	Financial resources; quantity and quality of human resources; organization of resources; independence and impartiality of experts (Smit and Wandel 2006; Engle and Lemos 2010)
Experience	Training and development; years of experience (Yohe and Tol 2002; Engle and Lemos 2010)
Leadership	Political commitment; initiation of partnerships; support for mobilization of resources; linking of actors; building trust among stakeholders (Tompkins and Adger 2005; Olsson et al 2006)

Source: Based on Engle and Lemos 2010; Hill 2011.

reactively to and to cope with hydroclimatic shocks (e.g., floods and drought, interannual variability, and predictable uncertainty) but also to proactively plan for longer-term shocks (climate change impacts and increasing unpredictability and uncertainties) (Tompkins and Adger 2005).

Adaptive capacity is a central feature of resilience: it is the ability of a social–ecological system to absorb disturbances while retaining the same fundamental structure, function, and identity (Carpenter and Brock 2008). Adaptive capacity should contribute to enhancing resilience rather than lead to adaptations that degrade resilience at different temporal and spatial scales. These challenges of scale are particularly relevant in mountain contexts because of the significant influence of external factors on both social and ecological aspects of mountain regions (Wiegandt 2008). Institutional and governance aspects, such as legislative and regulatory frameworks, policies, rights, and formal and informal institutions, have all been shown to be key determinants of building adaptive capacity and resilience at local, regional, and national levels (Adger et al 2005; Brooks et al 2005; Nelson et al 2007). Table 1 presents an overview of the determinants relating to governance that have been discussed as being important to the nature of adaptive capacity and to affecting the outcome of adaptive actions (Hill 2011).

Some studies have begun to assess the nature and potential outcomes of adaptation policies and plans to better assess how they might be positioning the systems that they govern along a trajectory that can increase their resilience to a number of environmental challenges at different scales. Adger et al (2011) demonstrated that short-term adaptation actions in some cases are undermining long-term social–ecological resilience or resilience to another stressor. Adaptive capacity should therefore contribute to adaptations (adaptive actions and associated governance mechanisms) that enhance resilience, by sustaining and enhancing ecosystem services, societal development, and human wellbeing (Folke et al 2010), rather than degrade resilience, either through a failure to adapt or a maladaptation (Chapin et al 2009).

Methods: assessing adaptive capacity

This study draws on these bodies of work (adaptation, vulnerability, and resilience) to assess the Swiss and Chilean water governance system's ability to cope with climate change variability and change. It uses system responses to past climate variability (in this case, past extreme events) to enable the identification of system attributes that are key to different adaptive responses (Smit et al 2000) (Figure 1).

After identifying key governance and institutional determinants of adaptive capacity (Table 1) in an initial literature review, a set of governance-related adaptive capacity indicators (Table 2) was operationalized and used to explore adaptive behavior within the context of the key extreme events identified.

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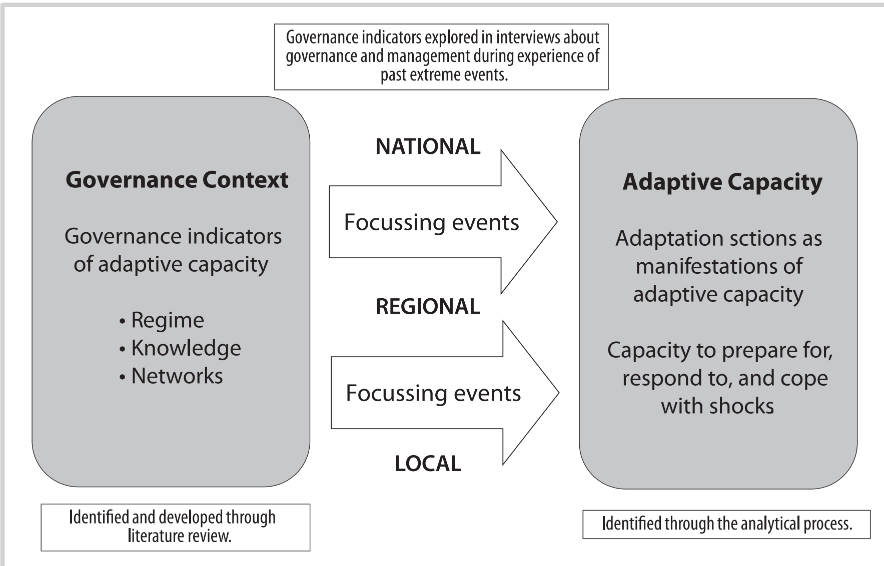
FIGURE 1 Analytical framework detailing causal mechanisms and methods.



For the purposes of this study, adaptive actions are seen as manifestations of adaptive capacity, represented by changes in the system that aim to deal with impacts from climate and environmental changes to which that system is vulnerable (Smit and Wandel 2006). Here, adaptive actions are defined as a response, institutional, or governance mechanism (law, regulation, policy, or institutional action; e.g., decisions or rules of user group associations) at national, regional, or local (both community and individual) scales that provides guidance or instruments for preparing or responding to different types of environmental phenomena (i.e., interannual

TABLE 2 Overview of adaptive capacity indicators used to explore adaptive behavior in the context of extreme events.

	Indicators		
	Regime	Knowledge	Networks
Criteria	**R1.** Consistency, certainty, and clarity of water rights and resources **ownership**	**K1. Evaluation and planning** for both short- and long-term hydroclimatic issues based on accurate and appropriate data	**N1.** Mechanisms to incentivize **cooperation** among water stakeholders within a basin to negotiate and resolve conflicts
	R2. Clear coordination of **responsibility** and rule setting and of conflict resolution	**K2.** Consistency, accuracy, and coverage in **monitoring and assessment**	**N2. Participation** to provide a voice in decision making across water stakeholders
	R3. Preparedness and flexibility in rules to manage hydrological extremes	**K3. Transparency**, availability, and accessibility of information on water resources	**N3. Knowledge partnerships** to share best practices and integrate scientific information into decision making
	R4. Integration of provisions for environmental and social sustainability	**K4. Perceptions** and awareness of climate change impacts, and openness to learning and adopting new solutions	**N4.** Clearly defined roles, **coordination**, and balance of power across institutions
	R5. Accountability and enforceability of regulations	**K5.** Mix of disciplines, **experience, and expertise** for holistic solution building	**N5.** Relative authority, agency, and autonomy across different **levels of decision making**
	R6. Effectiveness of institutions and implementation capacity		

http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00106.1

TABLE 3 Background on system stresses and governance context for the case areas.

Case study variable	Case study area	
	Region V, Chile	Canton Valais, Switzerland
Climate	Semiarid or Mediterranean Bivopluvial regime	Mediterranean Nivopluvial regime
System stressors	Legal and illegal abstractions reducing river levels and sustainability of aquifers Increasing urbanization and water pollution	Large concentration of hydropower production leading to intersectoral management challenges Ski and tourism area leading to seasonal peaks
Governance context	Water rights are a marketable commodity (1981 Water Code) with minimal environmental regulation and no sectoral prioritization. Government institutions are highly centralized, with limited agency and capacity of water managers at the regional level. Enforcement of usage or extraction and management of water use and rights rests with the water rights holders.	In this highly decentralized country, federal laws on water uses and protection and water course management must be transposed to state level. Communes are the functional entities for water management. There is a mixture of public, private, and common property rights for water resources. In Canton Valais, the communes are the main water rights holders for the tributaries to the Rhone, while the canton is the owner of water rights of the Rhone.
Focusing events	Droughts in 1996–1998, 2003, 2008, and 2010	Flooding events (1993 and 2000), scarcity periods (2003), seasonal peaks and scarcity because of the tourism sector, rain shadow leading to highly variable precipitation at different elevations

variability, drought, floods, and climate change impacts). As a next analytical step, these actions were characterized by the governance scale at which they mainly took place, the reactive or proactive nature of the action, and the associated impacts on social and ecological resilience.

Qualitative data was collected through a series of semistructured stakeholder interviews with national, regional, and local water governance stakeholders and experts (Chile, $n = 34$; Switzerland, $n = 29$; see *Supplemental data,* Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00106.S1, for more information on interviews across sectors and scales), participation in workshops ($n = 2$), and archival data analysis (legislation and regulation, policy documents, journal articles, and gray literature). Both the interview and the archival data were coded using computer-assisted qualitative analysis software (MaxQDA) and then analyzed to assess the evidence according to the adaptive capacity indicators and the categories of adaptive action.

Case areas: governance and climate background

Table 3 provides an overview of the governance context and water resources background of each case area. The Aconcagua Basin in Region V, Chile, is experiencing increasing pressure on its water resources from both climatic and nonclimatic pressures, leading to heightened competition among users for water allocation (Pellicciotti et al 2007). The Aconcagua is one of the only basins in Chile not regulated by a major dam, with the reputation to date of having sufficient hydrological resources and highly suitable climatic qualities for agricultural production. As overexploitation and a diminishing contribution from snowpack and glacier melt is leading to a hydrological deficit, however, local actors have demanded that the Aconcagua River be more regulated, with the construction of 2 new dams and a battery of wells (Matta 2011).

Studies in the region have shown that there has been a significant decrease in the annual and seasonal trends of runoff, related to decreasing contributions from glaciers and snow cover (Pellicciotti et al 2007). Compounded by increasing water abstractions, these impacts have led to a reduction in surface water recharge that tends to affect water rights in the medium and lower segments of the basin more severely (Desmadryl 2010). A number of droughts have affected the Aconcagua region in recent years, the most severe of which were in 1996–1997 and in 2010–2011. The Aconcagua is split into 4 sections, and not all sections of the basin are evenly affected by drought impacts because of the high hydrological and geographic diversity in the basin. Severe droughts have affected drinking water distribution and significantly reduced the availability of water rights to irrigators.

Climate change impacts are also being observed in the Upper Rhone Basin in Canton Valais in Switzerland, affecting glacier mass balance, snow cover, precipitation totals and intensity, and natural hazards, including geomorphological events (Beniston et al 2011). To date, stakeholders have viewed drought and scarcity impacts as

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being relatively minor in comparison to the recent experience of flooding events. For example, in 2003, despite the very low precipitation levels (a mean of 30%, according to MeteoSwiss data), water in the streams and rivers was plentiful from the record glacier melt (Huss 2011), meaning that the Valais experienced the opposite problem of that in the rest of Europe. However, local situations of scarcity were assigned to drier summers, leading to lower recharge levels in the springs. From the mid-1980s, a series of heavy precipitation events occurred at relatively short intervals, leading to major infrastructural damage and human casualties (Amweg 2011).

Results

This section first presents the main adaptive actions identified in each case area and then reviews the evidence according to the adaptive capacity indicators.

Adaptive actions

Across both cases, a number of key governance and institutional mechanisms were identified that were mobilized for, drawn on, or are relevant to preparing for or dealing with the case events in each case area, as shown in Table 4. To better indentify the type of adaptation occurring and its relationship to resilience at different scales, the adaptive actions in Table 4 are also characterized according to whether they are predominantly reactive or proaction mechanisms and whether they principally address climate variability (variability) or climate change impacts (change). This is further examined in the later discussion on scale.

Adaptive capacity indicators

The previous section described the adaptation context of the 2 cases. This section provides some insight into the governance and institutional processes that enable or hinder these actions and accordingly explores adaptive capacity indicators.

Regime: In both case areas, actors at the national and regional levels pointed to attempts to improve integration across scales of governance and sectors to provide a more coherent and coordinated response to hydrological challenges. In both case areas, progress toward this goal remained a challenge (R2). In the Chilean case, many interviewees point to the informality, weakness, and impotency of the Ministry of Public Works, the Dirección General de Aguas (Directorate of Water, DGA), and the Ministry of Environment to regulate water uses and enforce weak protection provisions (R1 and R4), leading to environmental degradation and overexploitation of water resources (R5 and R6). Furthermore, the informality of the Chilean governance approach in "normal" periods leads to a lack of capacity and knowledge of the river when the "external" DGA takes over at the most critical moment (R3 and R6).

While the Aconcagua project is seen by many agricultural stakeholders at the local level as the only means to enhancing the capacity of the system to cope with increasingly dry periods, frustration is high that negotiations have run for more than 10 years without resolution on the water rights required because of disagreements between agricultural stakeholders and the Dirección de Obras Hidráulicas and the DGA over the availability of water rights (R1) for filling up the reservoir (Matta 2011). The DGA is under pressure to allow the plan for the dam to be approved but posits that as there are no more available rights in the Aconcagua Basin and irrigators must use their own rights to stock the dam (Matta 2011).

In the Swiss case, the rules and regulations that guide water pricing, provision, and use tend to be set at the commune or cantonal level, including concessions and agreements for hydropower, allowing some flexibility in revising rules to adapt to emergent challenges (R1 and R3). While the decentralized and participative system and "subsidiary of implementation" ensure a consensus is built, it also means laws can be difficult to implement and the process of change or implementation is slow and potentially difficult (Uhlmann Brögli and Wehrli 2008) (R5). However, local sovereignty and the length of hydropower concessions (up to 80 years) mean that windows of opportunity for revision seldom appear or that cantonal or federal oversight can be weak or limited (R3). Furthermore, while legal guidelines exist for the management of increasing flooding issues, there is a void of guidance and rules on scarcity or stress (R3). Authorities highlighted the importance of provisions for financial incentives associated with ecological and social benefits (R4) as a vital means of addressing intrajurisdictional challenges (R6).

Knowledge: In the Chilean case, significant challenges remain in developing and sharing adequate data to effectively manage water quality challenges and administer the allocation of water rights (K2 and K3). Resolution 39 of the Water Code establishes the 3 criteria for the DGA regional office to call a period of drought, but the regional DGA office no longer perceives the data and requirements as relevant to or useful for current hydroclimatic conditions (K1).

The Aconcagua project is defined by criteria adhering to steady-state resource management, because there is no accounting for uncertainty or for incorporating interannual variability; there is also no integration of climate change–related uncertainties into the project scoping phase (K1). At the canal and river level, information that would enable more proactive planning (K1) is lacking. When the DGA does intervene, this implies a loss of knowledge; government actors are seen by the

TABLE 4 Adaptive actions categorized by scale and characterized according whether they are reactive or proactive, as well as addressing climate variability or climate change. (Table continued on next page.)

Case study	Adaptive actions		
	Level	Description	Characterization
Region V, Chile	National	**Water Code (art. 314)** provides for a presidential decree of a drought (maximum 6 months); DGA may intervene—on users' request—in the management of the river and redistribute water allocations. The code allows for extraction of superficial or subterranean waters without rights and prioritizes human consumption.	**Reactive/Variability:** Further exploitation of groundwater resources during drought enhances ecological vulnerability
		Resolution 39 establishes 3 criteria for the DGA regional office to call a period of drought based on data from 1984.	
		Law on Promoting Irrigation Efficiency (14.450) provides financing and subsidies from the National Commission of Irrigation to farmers to improve irrigation efficiency.	**Proactive/Variability:** In effect, but losing institutional support
		DGA, Since 2010, has prioritized improving the transparency and accuracy of the public information system (Cadaster Publico de Agua) for water rights to enable better water resources management under increasing scarcity conditions.	**Proactive/Change:** Enhances depth of and access to environmental data
	Regional	**Aconcagua project** was initiated in 2001, with the purpose of constructing a major new dam and 2 other minor dams and a battery of wells to improve irrigation security and allow for water transfers to La Ligua (a nearby drought-prone area).	**Proactive/Variability:** Steady-state focus on increased exploitation and irrigation security
		***Turno* between sections** is the process employed during drought periods to manage a proportional reduction of water rights and distribution of water to different users on a specific daily schedule.	**Reactive/Variability:** Potentially minimizes ecological impacts, but social injustices have been reported
	Local	***Turno* between canals** is the process employed during drought periods to manage a proportional reduction of water rights and distribution of water to different users on a specific daily schedule.	**Reactive/Variability:** Potentially minimizes ecological impacts, but social injustices have been reported
Canton Valais, Switzerland	National	**Federal directives and subsidies** enable incentives for implementing "resilience-based" water infrastructure projects and are linked to the implementation of federal legislative principles through the *Neugestaltung des Finanzausgleichs* (Reorganization of Financial Equalization/Compensation between the federal and the cantonal governments).	**Proactive/Variability:** Promotes ecosystem resilience, integrative risk management, and participation in water management

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TABLE 4 Continued. (First part of Table 4 on previous page.)

Case study	Adaptive actions		
	Level	Description	Characterization
	Regional	**TRC** is supported by federal and cantonal laws on management of watercourses and is a major project to reinforce flood security in the Rhone valley, with a number of subobjectives to enhance social, ecological, and economic security and wellbeing.	**Proactive/Change:** Incorporates ecological resilience and climate change uncertainty
		Modélisation des Intempéries de Nature Extrême dans le Rhône Valaisan et de Leurs Effets (MINERVE) is a public–private partnership to improve the modeling and enhance the speed and efficacy of the response network to extreme precipitation events.	**Reactive/Change:** Develops new stakeholders and networks
	Local	**Intercommune consolidation** brings more communes into a shared water utility service provision to spread water reserves and risks across hydrologically diverse communes.	**Proactive/Variability:** Better manages high demand or scarcity
		Intra- and intercommune contracts and agreements are commune directives for reducing water use in periods of drought. Private contracts and agreements are used to periodically transfer water to other stakeholders or uses. The traditional *suonen* or *bisses* are a common property resource regime initially developed and constructed in response to the dry climate and rain shadow effect and are still in some cases used to manage local rivalries and govern the water system among farmers.	**Reactive/Variability:** Ad hoc transfers water to farmers for irrigation or ski operators for artificial snow

irrigators to lack familiarity with the basin, because water management is usually in the hands of private farmers (K5). While there is a strong awareness among water owners that hydrological patterns are shifting, this has not yet translated into enhanced use of technology, monitoring, modeling, or integration of uncertainty into the management and planning of water resources in the basin (K4).

In the Swiss case, there is a lack of preparedness and planning for possible local scarcity situations in the area of water supply (K1). This is seen as being related to the perception of climate change as an issue for long-term horizon planning (30–40 years) but not yet one for operational day-to-day management (K4). While there is an acceptance and awareness of the inevitability of increasing impacts in flooding and natural disasters, awareness of other impacts of climate change related to water availability remains less engrained (K4). Despite this, there is still awareness among technical experts that precipitation patterns are changing and that legal mechanisms for drought are no longer up to date (K3 and K4).

However, the Third Rhone Correction (TRC) project brings together multidisciplinary experts (K5) and explicitly aims to allow the integration of potentially increasing levels of flows through an iterative review period (consistent integration of climate change projections and longer 10- to 20-year review periods), as well as through flexible buffers (e.g., evacuation corridors and buffer zones). However, the challenges of passing its implementation plan at the local level have led to a dilution of the elements that enhance the ecological and social aims of the project. Monitoring and assessment networks are maintained and used across multiple levels and sectors (K2), and there are a number of federal and regional studies and collaborations on long-term climate change projections (K1) in the Swiss case. In both cases, however, observational awareness of climate change

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impacts do not automatically translate into an integration of climate change–relevant adaptation strategies for coping with the longer-term impacts of the change that is being observed (K4).

Networks: In both case areas, there are challenges and impediments to the effectiveness of existent networks in the face of challenges relating to climate change. Stakeholders across both case areas, predominantly at regional and national levels, cited the importance of research networks and knowledge partnerships in developing their understanding of the challenges of and solutions to climate change impacts (N3). In Switzerland, regional stakeholders indicated the strength of support networks across cantonal levels, particularly for training and the discussion of challenges on the horizon (N3). In Chile, research partnerships were not as predominant a factor as in the Swiss case, but their importance for developing understanding and their capacity for problem resolution were noted across all levels of governance (N3).

In the Chilean case, while there is a willingness to cooperate on single projects for shared benefits that constitute hard infrastructural adaptations (e.g., reservoirs and wells), connections among actors tend to be based on financial or economic incentives alone, with no other glue binding actors together or providing an opportunity for participation (i.e., basin planning for a stable and sustainable system is lacking) (N1 and N2). The lack of trust among actors is seen as a major impediment to fostering integrated solutions to common problems (e.g., impasse over the Aconcagua project has lasted 10 years) (N1).

Furthermore, the DGA perceives that the agricultural actors have strategically used legal mechanisms such as drought provision as a means of forcing the DGA's hand on groundwater exploitation (N1 and N5). At the ministerial level, the power imbalances between different ministries and government institutions (mining, energy, and agriculture versus environment and water) has so far continued to sideline the environment and weaker economic actors in water resource management (N4), limiting the scope for innovation for enhanced social–ecological resilience through cross-sector collaboration and cooperation.

In the Swiss case, the networks that exist tend to be sector specific but based more on expertise development than on specific projects (N3). Local autonomy and decentralization means that the canton plays a supporting role in conflict resolution and water governance (N1 and N5). Although it is the role of the canton to assist local-level actors (i.e., managers of the canal capture points, water utilities, etc) in finding solutions to water provision during critical dry periods, these actors have limited authority and capacity (N1 and N5). Although this arrangement enables local ownership of planning and issue resolution (N2), it can detract from a coherent and coordinated strategy across the basin and can take a long time (N4). Furthermore, the small-scale political arrangement of water management in the Valais heightens the difficulty for municipalities to coordinate uses and to comprehensively plan for longer-term challenges (N4 and N5).

The implementation phase of the TRC (Canton Valais 2009) is highly participative. The different segments of each project have their own local planning commission that includes the interested parties. However, the level of participation highly depends on local factors, with inclusion and collaboration functioning well in some areas but not so well in other communes (N2). Stakeholders repeatedly pointed to the lack of leadership across the canton and federal levels, despite policy guidance provided by the federal administrations for water and environment on integrated risk management, climate impacts, and integrated water management (N4). This perhaps highlights the hands-off approach that is taken in the decentralized system, where technocrats at the federal level can provide insights into thought leadership on water adaptation, but there is an aversion at lower levels to accept their leadership or authority and match research innovations with provisions for implementation at local levels (N5).

Challenges of scale

By looking across the different responses across the cases, it can be seen that a number of adaptive responses are not necessarily enabling enhanced adaptability to mounting challenges from climate change impacts. Linked with this challenge is the emergent tension of balancing guidance and certainty from higher levels of governance with flexibility and autonomy of users and rights holders at lower scales. It is a challenge that is heightened in times of stress in the case areas, which instigate a heightened involvement of central or regional government agencies, whether from a financial or from an organizational capacity.

Figure 2 consolidates the evidence presented in Table 4 to depict the predominance of adaptive actions that are responding to challenges at a particular scale but not necessarily enabling an adaptive capacity to prepare for changes or impacts at other scales. Many of the adaptive actions implemented at local scales are associated with reactive approaches to historical variability, drought, and scarcity but are limited in terms of scaling up to face more complex challenges at greater magnitudes of climatic extremes (with the exception to this being the drought decree in Chile). However, the top-down, more proactive approaches associated with higher governance scales face major challenges in implementation at the local or basin level in both case areas. In Chile, there is gridlock because of disagreements over rights in the Aconcagua project. In Switzerland,

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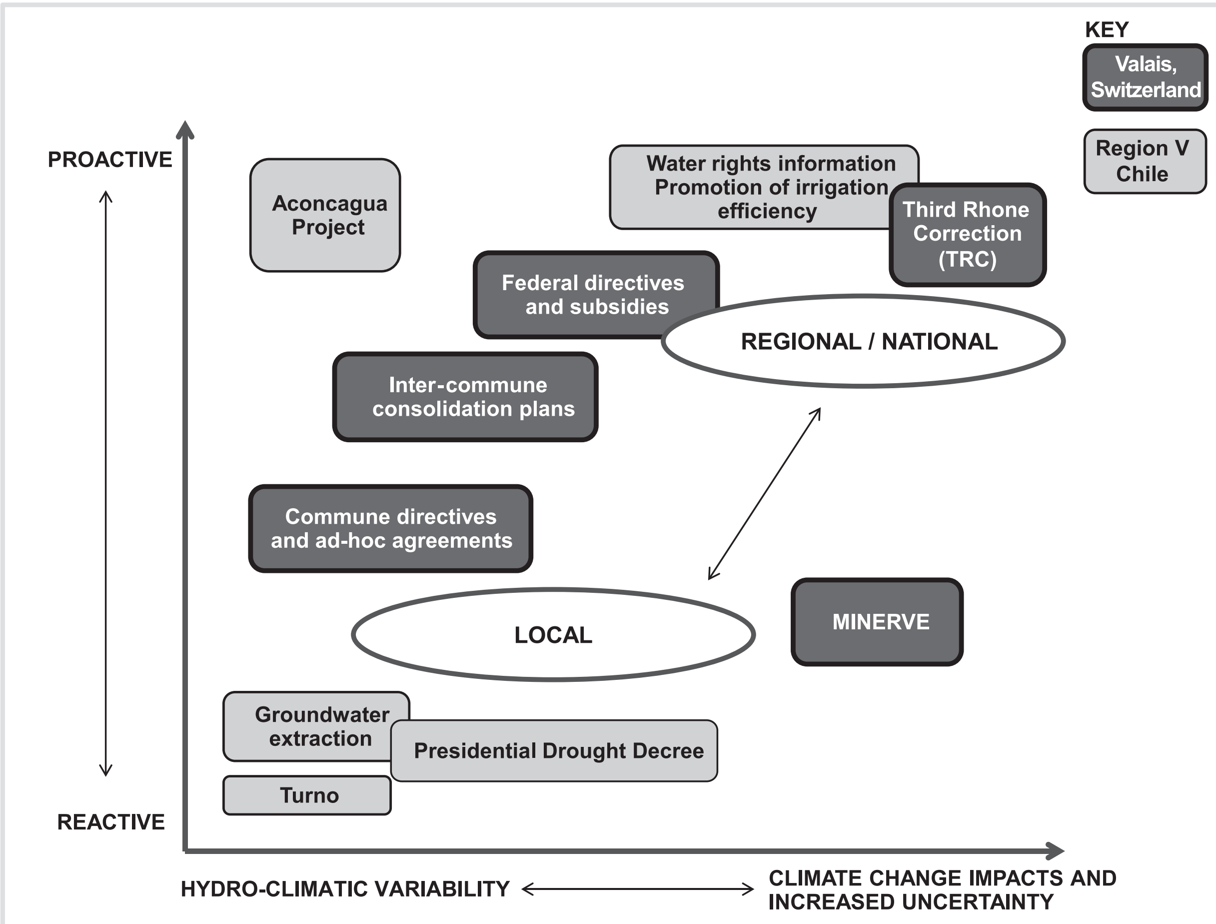
FIGURE 2 Examples showing the challenge of developing and mobilizing adaptive capacity to manage issues relating to different scales of change, as indicated by the multiple and sometimes competing scales at which adaptive actions are operating in each case. The double-ended arrow indicates the potential linkages and tradeoffs among these scales.



challenges of passing the TRC implementation plan at the local level are linked to disputes over land rights (NZZ 2009).

While both reactive and proactive approaches are of fundamental importance to adaptive capacity, case evidence, from Chile in particular, shows how a number of reactive approaches also lead to further depletion of increasingly vulnerable resources (e.g., increased groundwater exploitation and water transfers). Present coping techniques are therefore potentially degrading resilience of aquatic resources and ecosystems in the long run and in some cases are no longer seen as sufficient in the face of increasing levels and frequencies of drought.

Regime

In Region V in Chile, stakeholders pointed to the level of autonomy of the water rights as engendering a highly flexible and adaptive system, because they are not constrained by the inefficiencies of government and thus can self-organize to manage solutions at their level. However, in practice, water rights and legislation in Chile are based on principles that neither promote conservation or preservation of scarce resources (though efficiency is an aim) nor protect vulnerable riparian ecosystems (Bauer 1998), thus increasing vulnerability and limiting proactive development of long-term adaptive strategies to climate change.

In Valais, flexibility to act at the local level according to the needs and particularities of local characteristics is seen as vital for reactive approaches. However, the sovereignty and autonomy of the communes is simultaneously noted as a major impediment to developing cantonal oversight for a number of longer-term adaptation-related policies, such as the TRC, that aim to address larger-scale and more complex challenges at the basin level or changing hydroclimatic conditions.

Knowledge

In the Valais, Switzerland, with less experience of extreme drought and long experience of relative scarcity, stakeholders have a high awareness of climate change yet exhibit apathy in their ability to adapt to the longer-term impacts of climate change. Examples of collaborative and iterative science-driven projects can be found in the

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hydropower sector and the TRC project, which integrates climate projections in an iterative and integrative manner for sustainable watercourse management for both short- and long-term coping. Thus, while the series of flooding events were seen to serve as a wakeup call for political and policy action for developing a longer-term integrative and uncertainty-based approach to watercourse management, there has been less concerted action on scarcity, because alterations in water availability from diminishing glaciers and snow melt have been more variable across the canton.

In Region V, Chile, capacity challenges in the designated institutions for water management have led to challenges in developing the baseline of adequate data to effectively manage water quality challenges and administer the allocation of water rights. Therefore, the application of water and climate information to both short- and long-term water management decisions remains a significant challenge. Although there is evidence of climate change–relevant studies and evaluations being present across sector-specific institutions, there is a struggle to apply this information thematically to water challenges and to holistic water management planning.

Networks

Although both case areas are seen to have high levels of autonomy at local or user levels, factors relating to trust across vertical and horizontal scales lead to challenges in balancing flexibility and autonomy at different governance scales. In Region V, the lack of trust and lack of incentives limit basin-level collaboration for longer-term challenges. Issues around illegal extraction, nonfulfillment of spoken or written agreements, and mistrust of regional and national government actors were cited as major challenges by both local irrigators and regional water managers in managing drought periods. The Chilean case reinforces the evidence that in the absence of trust or respect for government, top-down rule setting can increase the challenges for enforcement and implementation (Ostrom 2010).

However, the Swiss case is defined by stronger networks for integrating knowledge and planning within sector networks at the regional level and across higher scales of governance (cantonal to federal). Despite high levels of expertise and strong networks across cantonal and federal levels, challenges relating to the limited authority and agency of regional and federal authorities in comparison to local communes constrict the development of longer-term adaptive mechanisms for cohesive responses to emergent complex climate change challenges.

Conclusion

Mountain regions where runoff is dominated by snow and ice are projected to experience significant shifts in hydroclimatic contexts that their governance systems will need to effectively cope with and adapt to (Beniston et al 2011). By looking across the different responses in these cases, it can be seen that a number of adaptive responses are not necessarily enabling enhanced adaptability to mounting challenges from climate change impacts. This problem can also be linked with the tension between balancing guidance and certainty from higher levels of governance on the one hand and flexibility and autonomy of users and rights holders at lower scales on the other. This calls for more investigation into how short-term adaptation actions may potentially be undermining long-term social–ecological resilience (Adger et al 2011), particularly in the multiscale and multisector policy context that frames adaptation, mitigation, and water resource management in mountain regions. While in recent years bottom-up approaches have been favored in the literature on adaptation, the present findings support other recent conclusions (Huntjens et al 2010) that more attention should be paid to how best to balance top-down and bottom-up approaches.

Water managers and stakeholders in these 2 case areas live in the shadow of "darkening peaks" (Orlove et al 2008), and both case areas demonstrate a high awareness of climate change impacts. However, discussion of the case evidence has shown that despite high awareness of climate change impacts in these regions, issues relating to water resources management information and a lack of trust and cooperation among stakeholders (across sectors and across governance scales) block larger-scale and longer-term solution building to overcoming complex challenges. These cases delineate the importance of building trust in enabling more adaptive governance and collective action for cooperative solutions to resource management challenges (Poteete et al 2010). A major challenge for both case areas is to shift the predominantly individual form of flexibility to one that is more cohesive for the generation of longer-term adaptive responses.

Acknowledgements of larger-scale changes are tempered either by apathy in the face of the scale of change or by perceptions that these changes will impact the next generation. However, the laws, contracts, and infrastructural projects that are being planned now will need to be relevant and adequate in 10 to 20 years, when the impacts of climate change will become more acute in mountains. Decisions made now could lock these communities into out-of-date rules, data, and infrastructure just as the agreements, projects, and contracts signed 20 to 80 years ago have locked in present-day management in both case areas (hydropower concession periods, water rights allocations, urban growth, and spatial planning). Both cases underline the need for water managers and policymakers to consider institutional aspects of adaptation as much as infrastructural aspects in climate change adaptation policy and planning. This could ensure that money and resources are not wasted on investments that may not resolve the key issues concerning water allocation and

http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00106.1

water resources management. Great effort to identify and resolve challenges in the social infrastructure might alleviate pressure on hard adaptations that are difficult to reverse in the future.

Finally, the threats that menace these precious mountain water resources because of climate change are also likely to have fundamental impacts on downstream uses and different economic sectors (Sundseth et al 2005). The adaptive capacity of mountain regions to climate change impacts is therefore significant not only for mountain communities but also for actors and communities at different spatial scales. It is therefore of high importance to ensure that adaptive actions happening at one scale (be it highland or lowland) are not degrading the resilience of other components of the social or ecological systems.

ACKNOWLEDGMENTS

This work has been supported by the European Union project Assessing Climate Impacts on the Quantity and Quality of Water (ACQWA) (Framework Program 7 of the European Commission) under Grant No. 212250. The authors also thank all those who took the time to be interviewed as part of ACQWA's governance research.

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Supplemental data

TABLE S1 List of interviewees, showing sectoral focus, governance scale, and case area.

Found at DOI: 10.1659/MRD-JOURNAL-D-12-00106.S1 (81.6 KB PDF).