Chapter 9
Converging Threats: Driving Pressures for Adaptive Capacity

Abstract Previous studies of adaptive capacity have shown the value in utilising past climate events to explore the experiences in mobilising adaptive and coping responses. The case events used in each case study area served as reference points of climate variability and as useful indications for the impact of extremes in a future, warmer climate. The exploration of past experiences in relation to climate related extreme events acted as a means to understand and assess adaptive capacity. This chapter details the extreme events used as focussing events for the exploration of adaptive capacity, as well as the attenuating management challenges which frame the context within which adaptive capacity must be mobilised. This chapter provides an in depth account of the focussing events, in the context of climate change impact projections, as based on interview data, archival data and primary research utilising meteorological and climate model data.

Keywords Rhône, Canton Valais, Switzerland • Aconcagua, Region V, Chile • Exploration of past climatic events • Coping and adaptation actions • Drought • Flooding

9.1 Switzerland

The climate of the Alpine region is characterised by Beniston (2004) as having a high degree of complexity due to the interactions between the mountains and the general circulation of the atmosphere. Resulting features of this complexity are the aforementioned rain shadow effect in the Valais as well as blocking highs and föhn winds. Precipitation patterns vary according to altitude, sun exposure (which is greater in the Southern Alps), and dryness of climate (Weingartner 2007). To date, the warming experienced in the Alps since the early 1980s has been roughly three times as strong as the global climate signal (Beniston et al. 2003). Broadly, climate change impacts in the European Alps will lead to higher winter temperatures and a

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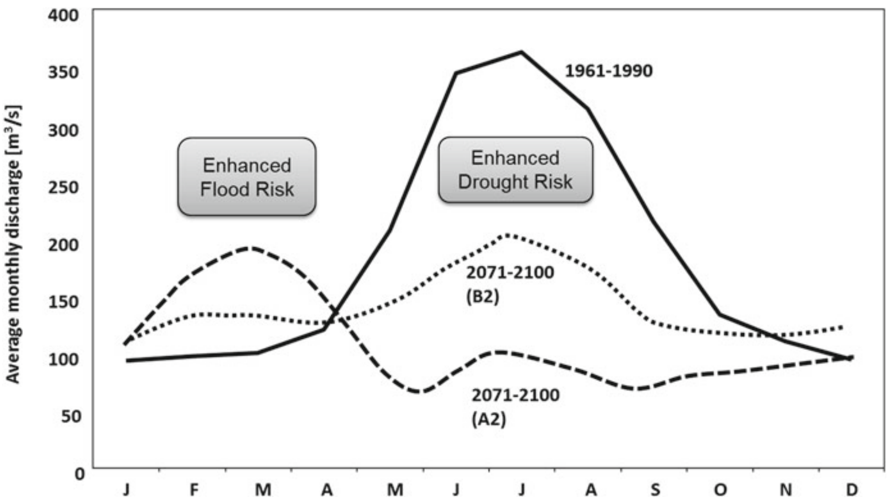

Fig. 9.1 Taken from Beniston et al. (2011) showing projected developments of flooding and drought instances for the Rhône Basin

more marked increase in summer temperature, higher precipitation that is more intense during winter, but likely to be much reduced in summer months (Beniston 2006). Increased temperatures will continue to have a significant impact on the melting of glaciers, whose thickness has already decreased by roughly five times more in the period 1980–2000 than during average loss (Büchler et al. 2004).

It has been suggested that the largest source of vulnerability from climate change is likely to come from changes in the intensity or frequency of extreme events, such as heat waves (winter and summer), heavy precipitation events and drought (Beniston et al. 2007). Increased glacial melt also is leading to an increase in flood risks and other natural hazard events (OcCC 2008). Figure 9.1 represents the difference in seasonal distribution of run off for the River Rhône between baseline values (1961–1990) and projected values for A2 SRES scenario (800 ppm) by 2100. The dark black line represents baseline run off, showing typical seasonal flows (high run off in summer, low in winter) for an alpine regime. The dashed line shows the 2100 projection, with increased run off during early spring and decreased run off in mid to late summer, while the dotted line indicates the intermediate alterations projected. The graph suggests that summer months could experience enhanced drought situations through reduced glacial mass and precipitation, while in winter months increased intense precipitation periods could not only impact on flood risk, but a wide range of geomorphological processes such as landslides and rock falls.

Increased flooding and extreme precipitation events are compounded by an increase in risk exposure due to infrastructure/housing development in vulnerable areas which are currently seen as ‘safe’ due to technical interventions. Temperature increases at alpine elevations raises demand for water uses such as artificial snow making and summer cooling and drinking water leading to complex management shifts, compounded by changes in seasonality. There have already been examples

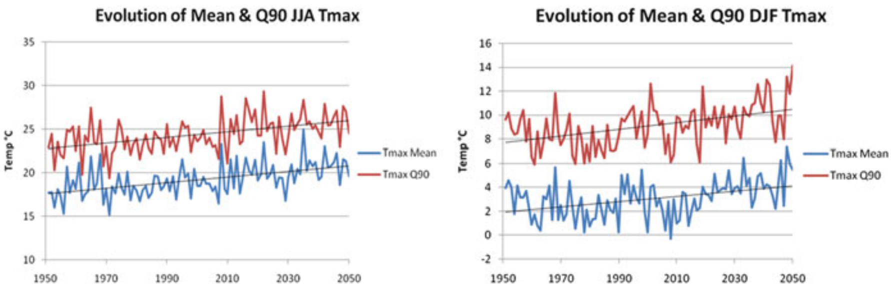

Fig. 9.2 Evolution of temperatures at Visp according to A1B scenario for summer temperatures (*left*) and winter temperatures (*right*)

where a lack of planning for drinking water supply has led to sector issues between hydropower use, tourism use and drinking water supply (Reynard 2000a), as well as tensions between the different sectors that arose in the 2003 summer heat wave, despite a paradoxical increase in surface flows in the River Rhône due to enhanced glacier melt.

The impacts of climate change may also compound the reduction in ecological status of many surface waters in Switzerland. Of 65,300 km of surface waters in Switzerland, 10,600 km have been considerably altered through technical projects, thereby impairing their ecological functions (FOEN 2009). Hydro-peaking (artificial high and low flow phases) also impacts rivers, in that they regularly dry up from over extraction of water, with damaging impacts on aquatic ecosystems. It is also worth mentioning the potential impacts of climate change on mountain forests, which have a variety of highly significant environmental benefits, including the protection against natural hazards (Gautam et al. 2004). Increasing temperatures and lower precipitation levels during the hottest periods are likely to lead to greater risk of forest fires, further increasing the vulnerability of mountain communities to the mounting hazards (rock falls, flash floods, landslides) from which they normally provide protection (Gautam et al. 2004).

Climate model data from the ACQWA project was used to calculate return periods as per A1B and B2 emissions scenarios. A synthesis of results from the stations at Visp and Zermatt are detailed below (Fig. 9.2). The figures show an evolution of higher mean temperatures for both summer and winter periods, with corresponding impacts on glacier melt that will influence the run off regime of the Rhône based as depicted in Fig. 9.1 above.

9.1.1 Focusing Events

To date, the Valais has been more seriously impacted by extreme precipitation events and flooding than by situations of drought and scarcity. Drought impacts were viewed by stakeholders as being relatively minor while extreme weather associated with high precipitation is seen as a much more significant issue. The issues associated with hydro-climatic extreme events have therefore been too much water, rather than too little water. This has meant that stakeholders have generally been preparing for increased periods of flooding, and little effort has gone into assessing relevant measures for water stress. Additionally, it was also noted, that it is also easier to work out how to cope with more flooding than with more drought.

It is worth mentioning the unique weather patterns that the Valais experiences; its relative dryness in comparison to the rest of the country (due to the rain shadow effect, e.g. Grächen has the lowest levels of precipitation in Switzerland), yet the extreme precipitation it often undergoes when warm air from the Mediterranean rises and releases huge amounts of precipitation in the area surrounding Simplon. This phenomenon of extreme dryness to extreme volumes of precipitation sets the backdrop for the focussing events that shall be discussed next. Valaisanne farmers have a long history of adapting to climate variability and dry conditions through the system of water canals (*Die Suonen/Les Bisses*). This system of canals that lead glacier melt water from the high alps to the alpine meadows continues to buffer farmers from the most extreme impacts of very dry periods such as the 2003 heat wave, since as glacier melt increases more water can be exploited through the irrigation infrastructure.

Generally, stakeholders concluded that in 2003, despite the very low precipitation levels (30%[1]), water in the streams and rivers was in fact plentiful from the record glacier melt (Huss 2011)[2], meaning that the Valais experienced the opposite problem to the rest of Europe because of this increased melt water. However, drier summers have been leading to lower recharge levels in the springs, which did require certain non-essential domestic uses to be stopped in places such as Visp (e.g. watering the garden, swimming pools, washing cars). Farmers were also required to stop using drinking water supplied from the utility to irrigate their meadows and fields in the area of Visp, and instead pumped water from the Rhône, as a one off adaptation to the extremely low precipitation levels. The commune is now implementing measures that would reduce the amount of water used for irrigation purposes from the local utility.

The extreme heat wave in 2003 did lead to some tensions between farmers who needed water to irrigate their fields, but mostly on the 'right' side of the valley (i.e. the northern alpine side), where the glaciers are not as high, extensive, or as numerous, and the distance to the valley shorter. Issues of scarcity also tend to hit at commune rather than cantonal level. The amount of water farmers receive is traditionally co-regulated, with each farmer knowing exactly how much water should be received over a certain number of hours. Problems have started arising after very dry winters, or winters with low amounts of snow,

[1] MétéoSuisse Data show that precipitation deficits range from 20% at Montana to 38% at Gd St Bernard. Therefore a median figure of 30% is seen to be representative of Valais as a whole.

[2] In August 2003, a recent study has calculated ice melt to have been over three times the mean (Huss 2011).

where traditional irrigation is not possible from the end of July onwards. For example, there are a number of communes (Bralanch, Gutthed, Faessil) above Leuk that in 2003 could not maintain irrigation from the end of July after a snow-poor winter, halting the second growth of grass for hay making due to lack of water in the streams.

For the hydropower operators, the 2003 summer heat wave meant a period of increased melt, and therefore increased production. For example, hydropower operators reported production that was about 20–25% higher than normal. However, some operators are concerned that maximum levels of run-off have now been reached and are unlikely to increase further. Between the 1960s and later 1990s to early 2000, stakeholders referred to the steady augmentation in melt, which has been seen to stabilise since 2000, mirroring studies that suggest a peak might have already been reached and thus the transition from a glacial to a nival run off regime may have already commenced (Huss 2011; Huss et al. 2008). In general, the operators tend to receive more water earlier in the summer melting, even if precipitation (as rain or snow) is reduced.

Low flows in winter exacerbate the already high pressure on multi-use rivers and streams in the Valais, where many rivers have already experienced some form of drying up because of over-extraction, in particular during peak vacation periods in this region, highly dependent on tourism for a significant part of its income. The drying up of rivers becomes apparent after August, where uses compete over less melt water in the late summer period (e.g. La Reche River) causing tensions between the fishery and environmental lobby and on the other side the agricultural and hydropower lobby. Peak periods of over demand (Christmas, New Year and Easter) occur at the lowest periods of flow (also when hydropower plants are capturing much of the water that would flow into the streams), but climate impacts can also aggravate these lower flows in winter, further damaging micro-organisms and fish.

From the mid-1980s, there were a series of heavy precipitation events that occurred in relatively short intervals. In 1987, Muster and Goms were heavily impacted, and then in 1993, heavy rain for a number of days resulted in destructive flooding in the Saastal down to Brig, where the damage from the debris flows through the heart of the city generated damage costs of close to CHF one billion (FOS 2011). The winter of 1999/2000 became known as the avalanche winter, and in the autumn of 2000 more major flooding events impacted Stalden, Baltschieder, Gondo and Brig as well as the lower Valais at Riddes. In Gondo, the event resulted in 13 dead, with practically the whole village being washed away (Amweg 2011). While in Baltschieder, about 80% of the sewage infrastructure was affected, and it took 5–6 years to repair. Stakeholders noted that while impacts on water provision from flooding events, impacts on sewer system and drainage infrastructure has tended to be much worse. While in all of these cases, it was the valley communes that were most significantly damaged, the initial increases in river water volumes started much higher up, at around 3,500 m.

Stakeholders allude to the shock at the increasing volumes of water that came down during those periods, the increasing frequency of events across the two decades as well as the increasing amounts of damage and destruction that they caused.[3] Some stakeholders suggested that the increased damage has been partly assigned to the relative failure of infrastructure that had not been as well maintained. The relative lack of experience of such flooding events in the previous decades (living memory of the hydraulic engineering or flood protection managers) had meant that they had allowed the built up areas to encroach on the river's space, giving the Rhône only as much room as it was thought necessary (about half as much as was sufficient for adequate protection). As soon as quantities did increase, and dramatically so in the series of flooding events, it became clear that high flows needed about twice as much room as currently was allocated. The increasing intensity of precipitation also has negative impacts on water quality and damages the catch points for water in the streams.

In 2000, damage was limited by the remediation enacted after the 1993 event, despite the fact there was about 25% more water, but those projects which were built around 20 years ago were already not enough to have the capacity to hold back future quantities. Some 350 m^3/s fell in the Vispa in 1993, which was exactly the limit that they could cope with. The first and second Rhône Correction projects were 100 and 50 years ago respectively, and the events showed how the dams were no longer stable enough nor had sufficient capacity for heavier precipitation events, therefore were insufficient for protecting the settlements and industrial areas bordering the Rhône. The new measures that have now been implemented are prepared for 550 m^3/s.

In addition to the impacts felt within villages and towns themselves, hydropower operators also experienced impacts on their reservoirs and operations. In 1993, the Mattmark dams amongst others overflowed, while the power station at Stalden was also exposed as being vulnerable to the flooding. The overflow from the dams exposed the fact that the storage volume of the reservoirs was no longer large enough to contain the volumes of water, in fact worsening the impact of the 'natural' flooding. In the 1993 case, the road was severely damaged between Mattmark and the valley as far as Saas Almagell and the village itself was also severely impacted. In the 2000 event, which took place over 3 days, there was a significant impact on operations. During this period, issues in how to regulate the hydropower reservoirs occurred between the canton and the hydropower operators, in that while they needed to discharge water from the reservoir, the overall management of the river was unclear. During a period of 3 h, around 30 m^3/s needed to be let out of the Mattmark reservoir, which is likely to have further impacted the intense flooding of the Rhône in Saxon.

It is not just the volume of water that affects the hydropower operations, but the extra volumes of material, such as sand, gravel, dirt and bed load which affect water quality, blocking or damaging the turbines. While from a profit perspective, the worst case scenario is that the installations need to be de-activated or are damaged, from an operational and river management perspective, it is that the reservoirs or facilities overflow and aggravate the flooding that impacts the villages further downstream.

[3] For example in the 1993 event, about 80 m^3/s fell, and then in the 2000 event, 125 m^3/s fell.

With the Mattmark reservoir, extra storage capacity can be created by pumping water out of the reservoir to prepare for higher precipitation volumes as and when is needed. In 2000, a debris flow (*murgang*) caused extensive damage to the Vispa in Stalden. During this event the extra storage volume was used to ensure that excessive amounts of water did not flow into Visp, hence avoiding more serious flooding impacts, although some damage still occurred.

The Third Rhône Correction plan was outlined in the aftermath of the earliest of these events, and agreed upon after the later events, as the impacts of the floods highlighted how the earlier remediations on the Rhône (the first and second Rhône corrections) could no long ensure sufficient security for the Rhône flood plain. In the central Valais, there are a number of priority measures (e.g. at Alcom) because it is an industrial zone where they produce aluminium, and the damage potential is millions of franks worth. The 2000 flood was a prime example of the increasingly aggressive autumn floods that occur between September and October, when a cold snow spell is followed by higher than average temperatures.

While the elevation of the snow line has significant implications on the alpine tourism industry, there are also severe ramifications for water quantity and timing and the impacts from heavy precipitation events. For example, in the Valais above 2,000 m the terrain tends to be mainly glacial or rock and cliff. When the 0°C isotherm is only at 4,000 m as opposed to about 2,000 m, then most of the precipitation falls as rain, rather than snow, with repercussions for the amount that is stored for later melt (Beniston 2006), and that which flows down directly through the streams and off the cliffs (a 2,000 m difference can increase or reduce the volume by half).

Increasing flows of water from rapidly receding glaciers is not only an influencing factor on the increasing flooding events, but also provides certain benefits to the hydropower operators, who have more seasonal production than when the 0°C isotherm is lower. Changing patterns in glacial melt have had repercussions on spring levels, which are fed by seasonal glacier and snow melt. At the commune level, the largest source of water for domestic supply is from glacier melt (in that it feeds the springs and groundwater from which domestic use is supplied). In the Zermatt region, the rapidly reducing Findler Glacier is negatively affecting spring recharge, which the communes rely upon for domestic water supply.

In other areas of the Valais, there are situations where levels of melt water are insufficient to meet demand from mid-August (but mainly on the northern alpine side). Low snow levels in winter and periods of low precipitation in summer, also negatively impact spring levels, which can lead to an increasing exploitation of groundwater sources. Spring and groundwater levels are dependent on a number of variables, including precipitation levels in winter, whether precipitation falls as rain or snow, and when the melt period begins. In general, if the months after March are very dry, then the dual impact of less melt and less precipitation reduces the replenishment of the springs (April 2010 and 2011 were both extremely dry). These compounding impacts have reportedly led to situational increases in competition at the commune level, for which the canton has no oversight. However, while utilities have diversified supply from precipitation (rain/snow) and melt water to recharge springs, hydropower operators rely solely on glacier melt.

To date, winter heat waves have not been observed to have a major impact on river levels, partly because the glaciers and water capturing points in the Valais are at high enough altitudes, that temperatures remain negative. Additionally, rivers in the Alps are at their lowest levels during the winter months, therefore any increase of melt would have been adequately absorbed by relatively dry waterways to avoid sudden flooding. Stakeholders also referenced noticeable changes in invasive and damaging species such as the Colorado Beetle, which is now recorded at higher altitudes, affecting different crops such as potatoes. Additionally, melting permafrost has also led to increasing problems of landslides and rock falls where previously there had been none. However, permafrost is not a climate impact that will be explored further in this chapter.

9.1.2 Converging Threats: Non-climatic Drivers

In addition to the specific impacts from climate related stresses as detailed above, there are a number management related challenges that were identified through the coding exercise as converging threats within the basin. Most of these issues have already been addressed in Chaps. 1 and 4 and were presented through the broad governance context in relation to indicators of good governance and IWRM (Chap. 5). The issues highlighted in this section (and in the following Chilean section) relate mainly to specific geographical, demographic and infrastructural issues that interact with the climate driven issues and so in some respects are difficult to separate from the climatic drivers of adaptation responses (see Sect. 6.2.1 for a definition of response).

Perhaps the biggest management challenge for the mountain municipalities is the issue of periodic rivalries. Peak period demand, when water flows are at their lowest, are precisely when water demand is at its highest. For example, in Zermatt and Les Bagnes, 90% of demand is during winter and notably at specific points during winter. This requires a commune with a population of 3,000–6,000 to be able to cover water supply for an intermittent population of 30,000 over the course of a few weeks during the winter season (December–April), when the springs are at their lower. This has caused some local water managers to suggest that the communes will in the future need to rely more heavily on exploiting groundwater sources (Zermatt is currently fully dependant on spring water), if demand keeps rising, and their ability to recharge the springs during summer diminishes. A related impact of tourism peaks is the steady rise of electricity demand, which has risen by 3% per year for the previous 5 years, the majority in winter (EWZ 2010).

Despite the strong principles of decentralisation that defines the Swiss governance framework, concentrations of power have gradually been shifting from lower to higher levels of government as well as across private and public sector responsibility. Certain services that used to be the responsibility of private actors at the commune level have now been transferred to the public realm either at the commune or cantonal level, most notably after the 2000 flooding events. For example, reconstruction and repair of damages from extreme weather events is no longer managed privately as remediation work was so extensive it required the structure and support of the commune or cantonal authorities. In the aftermath of the 2000 event in Baltschieder, the commune and canton collaborated to take over the clean-up operation, rebuilding the streams and repairing the canalisation network. After the 1993 events, there was a realisation that the damage costs were so high, that the communes did not have the financial capacity to cover the bill. The canton therefore took responsibility for remediation costs, later sourcing percentages of repayment from both federal and commune authorities.

Despite these shifting demographic and political structures, traditional associations for the water irrigation channels have tended to remain, yet in a weakened form. As agriculture and the number of full time farmers decreases,[4] the number of members of these common property resource regimes (CPRs) is in decline. While water is linked to property rights in these regimes, many people who now own the relevant property are no longer farmers, but perhaps holiday or second home owners, and therefore no longer use the associated water rights or consider themselves responsible for paying for the upkeep of irrigation infrastructure they no longer use. Where these CPRs are dwindling, many of the activities are being transferred to the commune. Likewise, similar institutions and associations for more relevant needs are being discussed (domestic water, artificial snow) and additional financial support sought through organisations such as Berghilfe.

9.2 Chile

There has been very little documentation of the potential impacts of climate change in semi-arid watersheds in subtropical South America (Vicuña et al. 2011a), despite most climate models projecting a strong future climate change signal on the Western side of the Andes (Mata and Campos 2001; Souvignet and Heinrich 2011). Climate projections based on GCM's for central Chile[5] consistently demonstrate

[4] Alpine farmers have traditionally played an important role in the upkeep of the 'alpine cultural landscape', including the maintenance of traditional defences and infrastructure that play a role in water management and associated protection mechanisms against avalanches, flooding and landslides. As more and more alpine farmers move in either a full time, or part time, capacity to other economic sectors and financial resources are more constrained, infrastructure upkeep becomes more of a challenge at the same time as hazard recurrence is increasing (Kantonszentrum für Landwirtschaft; lack of upkeep on the irrigation system of Vispa, Saasvispa, Mattervispa meant that water was not as well transported through the canal system, and instead flowed wildly off the slops intensifying damage from the flooding event). In the Oberwallis for example 85% of farmers now are part-time, and often work either in tourism or in the Lonza factory (Kantonszentrum für Landwirtschaft).

[5] However, it should be recognised that 'because of the special physiographic characteristics of watersheds on the western slope of the Andes cordillera (steep, short river lengths, with a 3+ km elevation gain from the Pacific Ocean in less than 200 km), the spatial scale of current GCM modelling grids is inadequate to assess local effects on the hydrologic regime and downscaling approaches (statistical or dynamical) introduce an additional layer of uncertainty' (Vicuna et al. (2011a, b, JWRM).

both a warming and a drying trend throughout the rest of the twenty-first century (Christensen et al. 2007). Winter months (June–August) feature both minimum temperatures and maximum precipitation, namely about 80% of annual total precipitation between May and August (Vicuña et al. 2011a). Summer months (Dec–Feb) feature minimum precipitation and tend to be snow or glacier melt dominated, with the main proportion of stream flow taking place in late spring and summer (Sep–Jan) (Vicuña et al. 2011a). This leads to almost total reliance on glacier and snow pack melt for water during the growing season, in areas where there is no storage capacity. Climate change associated reductions in run-off, hydrograph timing and enhanced evapo-transpiration will have significant impacts on agriculture in the semi-arid areas of northern and central Chile (Vicuña et al. 2011b).

Furthermore, precipitation and temperature are both strongly influenced by different large scale natural phenomena such as ENSO as well as, the Pacific Decadal Oscillation (PDO) (Garreaud et al. 2009; Souvignet and Heinrich 2011; Verbist et al. 2010), leading to high inter-annual variability (Vicuña et al. 2011a). ENSO is a coupled ocean–atmosphere phenomenon, tied to the tropical Pacific Ocean, that is characterised by fluctuations (periodicity between 2 and 7 years) between a warm phase (El Niño), generally associated with higher than average precipitation in central Chile, and a cold phase (La Niña), associated with lower than average precipitation (Garreaud et al. 2009). While ENSO is observed as the primary driver of inter-annual variability, PDO has been suggested to force decadal and inter-decadal variability, with temperature and precipitation anomalies related to ENSO, but with smaller amplitude (Garreaud et al. 2009). In the preceding decades, ENSO events have become increasingly frequent, but high levels of uncertainty mean that projecting its development according to climate change scenarios is still poorly understood (Kim and An 2011).

While glacier shrinkage in the Dry Andes (generally between 20 and 35 S) has been relatively well captured (Le Quesne et al. 2009), the impacts on stream flow have been less well documented, in part due to the challenges of data collection (Gascoin et al. 2010). Despite high uncertainty and general lack of data on climate change impacts in the central Chilean region, studies and observation show that in the Aconcagua Basin, there has been a significant decrease in the annual and seasonal trend of streamflow from the Aconcagua basin glaciers, related to decreasing contributions from glaciers and snow cover (Casassa et al. 2009; Pellicciotti et al. 2007). Pellicciotti et al. (2007) suggest that melting rates tend to be higher in the Central Andes, since the glacier ablation area occurs at lower elevations and so higher temperatures in summer have increased melting. Furthermore, simulations in northern central Chile suggest that the Dry Andean mountain range is likely to encounter warmer winters, decreasing precipitation, changes in snowpack, changes in snow and glacier melt and generally increasing dry periods, though as mentioned earlier, this is still poorly modelled by GCMs (Souvignet et al. 2008; Vicuña et al. 2011b). As Vicuna et al. (2011b, p 482) clarify ‘increase in temperature leads to a reduction in snowpack accumulation during the rainy season and an earlier, faster snowmelt process during spring and summer’.

The changes in amounts and timing of hydrological resources converge with enhancing levels of water demand from growing urban populations, irrigation areas and mining activities (Reyes Carbajal 2007). Beyond the challenges implied by decreasing amounts of water resources for economic inputs, increasingly dry conditions in the spring and summer months would also have severe consequences for the farmers in the agricultural belt that is situated in central Chilean areas, through impacts in the biological productivity of ecosystems (Vicuña et al. 2011b). Changes in stream flow timing and amounts already have begun to impact the different economic sectors in the Aconcagua, and shall be further discussed in relation to the focussing events below.

9.2.1 Focusing Events

Over the past 15 years, while there have been a few flooding events associated with increased snow melt and heavy precipitation events, drought has been a far greater preoccupation of water stakeholders with far reaching impacts for the SES. Andean watersheds generally experience low precipitation in summer and rely heavily on storage of winter precipitation within the snow pack and glaciers of the high Andes. Climate change impacts on water quantity have already led to increased water stress, which compounded by increasing water abstractions, has led to a reduction in surface water recharge that tends to impact water rights in medium and lower segments of the basin more severely (Desmadryl 2010). Melting glaciers and reductions in water availability have also been observed to have exacerbated impacts on water quality, ecosystems and overexploitation of certain aquifers in the northern and central regions. With around three quarters of Chilean economic produce and activity seen as water intensive, the repercussions from climate change impacts on water reserves with far reaching potential consequences (Desmadryl 2010).

In the preceding 15 years, there have been a few incidents of the river overflowing, such as the 2009 event in the Panquehue region, primarily from increased flow due to ice melt in spring time. DOH has undertaken a number of remediation works, and in the past 6–7 years, there have been no major issues from flooding, but also no major substantial overflows either. Vulnerable areas are situated at La Calera, Panquehue and Los Andes. Increasing variability is seen to reduce the former predictability and the innate knowledge of precipitation volumes, snow fall and flow behaviour. In May 2010, a combination of precipitation in the high mountains and ice melt during summer led to increased run off and thus an overflow of the river.

The natural reservoir of the region, ‘La Cordillera de los Andes’ has already been exposed to a rise in the zero-degree isotherm, reducing the capacity of snow storage and thus further aggravating over exploitation of surface waters during the dry summer months. Combined with the potential diminution in run off contribution from melting glaciers, the scarcity situation of the basin has been deteriorating in the past years. While there have been a number of droughts in recent years in the

Aconcagua region, 1996/1997, 2002, 2008 and most recently 2010/2011, the most severe were those in 1996/1997 and 2010/2011. While stakeholders have known drought periods to occur about twice per decade, recently, an increase has been observed. In 2002, 2008 and then in 2010, an official drought zone was declared by the President with the support of the DGA. In 2010, the drought zone was declared on 25 November, while in 2008, it was January 1. The earlier the declaration, the more the DGA can try to mitigate impacts of the drought, which affect agricultural stakeholders and utilities most severely. In 2010, a significant reduction in snow fall, despite rain volumes remaining constant, was seen as the primary cause of the drought.

Not all sections of the basin are evenly affected by the drought impacts, due to the high hydrological and geographic diversity in the basin (see Chap. 4). While the third section is most sensitive to drought and the second section the least sensitive. Petorca and La Ligua are some of the worst affected areas, as they do not contain any surface water, but instead rely on groundwater rights extracted through deep wells. The impact of severe droughts, such as 1996, 2002, 2008 and the most recent 2010 droughts have impacted drinking water distribution. In response, the DGA was called on, through the official drought declaration, to identify the most important needs and distribute water in equal quantities for drinking water and agriculture. In the 2008 drought, there were water transfers by truck from Algibe to Ligua, and from Cabildo to Ligua, which is the capital of Petorca province. At the time of interview, the expectation was that this would need to be repeated in the 2010/2011 drought. There were also transfers to Limache, and a transfer from Quillota to Marga-Marga. The summer droughts are also aggravated by the large population surges in the coastal cities of Valparaiso, Viña del Mar and Reñaca during the warmer months.

Drought impacts are exacerbating issues of general over-exploitation of water resources in northern and central areas of Chile that had already led to decreasing levels of water availability. For *regantes* (farmers with water rights to irrigate) each drought period has meant a significant reduction in allocated rights. A number of instances of illegal abstractions from the canals were reported during interview. These illegal abstractions can take multiple forms, including the placing of pumps in the canals to extract their full rights allocation, or even position glass sheets in the canals so that the water can be 'invisibly' siphoned off. Often during such drought periods, the water might not reach the last farmer in a canal (as in the case of 2010 drought), even after interventions have been made. In addition to climate-related drought impacts, there are a number of aggravating factors that in themselves intensify drought related impacts, and are themselves aggravated during drought periods. Firstly, irrigators, utilities and water managers alike refer to the amount of water that is lost to the ocean due to the lack of storage infrastructure in the basin.

The Aconcagua is one of the only basins in Chile not regulated by a major dam (the only major dam in the region is in Los Aromas, in Section 4). This is partly attributed to the fact that the region has been historically known for sufficient hydrological resources and highly suitable climatic qualities for agricultural production, a situation that over-exploitation and diminishing contribution from snow pack and glacier melt has now reversed into a hydrological deficit. As climate change impacts further reduce the capacity of the Andean natural storage (i.e. glaciers and snow pack), irrigators and water managers have stepped up their demands for the increasingly drought-prone Aconcagua River to be more regulated, with the construction of at least two new dams, and a battery of wells.

9.2.2 Converging Threats: Non-climatic Drivers

While the focus has been on water quantity, a number of issues were raised by agricultural and utility stakeholders about the combined impacts of mining, urbanism and drought for water quality. ESVAL's water rights in Estero Riecillos, in the high Andes in the upper part of the watershed, have become increasingly impacted by the expansion of Mina Andina. Mina Andina is not only using water from Riecillos, but there are additional reports on the impacts of mining activities on the glacier itself, thereby further exacerbating the increasingly stressed situation. Transparency over mining activities or planned activities is difficult, but within the basin, it is common knowledge that CODELCO are constructing some of the largest covered mines in Chile (reportedly to be larger than Coquichamaca), but this evidence must be taken as hearsay since public knowledge is limited due to the secrecy of the company itself, and the lack of transparency concerning approved project plans, as well as the fact that water rights for glaciers do not exist.

Another aggravating factor on water quality is the increasing growth of urban areas, in particular the associated littering of vulnerable waterways (canals) with urban waste. Irrigators from the third section noted that they had to remove between 1 and 9 m^3 of domestic waste from the canals that passed near Quillota. The impacts from this pollution were intensified during each period of drought. Another issue that affects water resources across the central and northern parts of Chile is the over exploitation and illegal extraction of water resources, both surface and ground (including aquifers). Hydropower companies also have extraction points in the river (*compuertas*), higher up in the watershed, where water is pumped from one point in the river, used for electricity generation, and then pumped in at another part, creating relatively drier sections at the extraction points. Illegal extraction is not just an issue for water resources, but also in terms of ground bed of the rivers. Irrigators reported that the Aconcagua has recently been extensively, and illegally, mined, with stones and gravel removed from the river bed during recent construction of the state highway.

For example, between Punta del Rey and San Felipe in section one, reportedly 4 million m^3 of sand in the last 3 years, gravel and rocks had been removed from the river by different companies under the auspices of the state government. The law states that if you remove more than 100,000 m^3 of gravel from the river (Water Code, Art 32; Environmental Law, Art 27) then an EIA should be completed. In order to circumvent the law once a company removed 99,000 m^3, the extraction company was allegedly changed every 99,000 m^3 until the 4,000,000 m^3 reached for the project.

Irrigators believe that this removal has punctured the river's seal leading to a drop in water level, thereby further exacerbating low river flows during the present drought period of 2010/2011.

In the Aconcagua Basin, the different sections are characterised by different hydrological contexts. While Sector 1 is at the top of the watershed, Section 2 enjoys relative water abundance due to the upwelling in the area (groundwater meets surface water), allowing for comparatively simple illegal groundwater use. Sector 3 on the other hand is in a more resource scarce area, while Sector 4 sits at the end of the catchment at the mouth of the river and not only has low coverage of agriculture, but less water availability than the rest of the basin. These contrasting hydrological characteristics are attenuated by the fact that upstream water right owners are generally able to abstract their full allocation, while downstream rights holders then enjoy less valuable water rights due to their inability to guarantee flows being released to their sections.

Finally, the Aconcagua basin is characterised in part as one of the only in Chile not to have any major regulation works. Irrigation security due to lack of dams, wells and other major regulation works is therefore seen as one of the biggest issues in the basin, resulting in a 'loss' of water (mainly in winter – in the non-irrigation season) to the ocean. Additionally, a lack of investment and maintenance in the water supply channels is blamed for the general lack of impermeable irrigation channels across the different sections of the basin, particularly in the areas where the length of the channels exceed 40–50 kms. For example, the 140 km long Waddington channel in the basin experiences about 50% loss, which means that farmers at the end of the channel can on occasion receive no water at all (but instead just rely on groundwater abstraction). The Waddington was created in the early nineteenth century, with a soil bed that has settled over the years because of natural condition. Today, leaks have to be constantly adjusted and losses dealt with, yet it is considered too expensive to invest in the restoration and enforcement of the channels.

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