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Regional climate change and adaptation

The Alps facing the challenge of changing water resources

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Executive summary

Vulnerability of the Alps to climate change

Spanning the centre of continental Europe, the Alps play a crucial role in accumulating and supplying water to the continent. Recognised as the '**water towers of Europe**', the mountains host most of the headwaters of the rivers Danube, Rhine, Po and Rhone; as such, they deliver vital ecosystem services both within and beyond the region, underpinning social and economic wellbeing in vast lowland areas.

Troublingly, the alpine climate has changed significantly during the past century, **with temperatures increasing more than twice the global average**. This makes alpine mountains especially vulnerable to changes in the hydrological cycle and decreases in snow and glacier cover, which are already occurring. Global climate change threatens to continue altering the alpine hydrological system drastically. Projected changes in precipitation, snow-cover patterns and glacier storage will further alter run-off regimes, leading to more droughts in summer, floods and landslides in winter and higher inter-annual variability.

Projected water shortages and more frequent extreme events, combined with increasing water demand (for irrigating agriculture or tourist influxes, for example), are likely to have severe adverse effects on ecosystem services, such as the provision of drinking water. Furthermore 60 % of mountain plant species may face extinction by 2100 if unable to adapt by moving northward or uphill. Economic sectors, including households, agriculture, energy production, forestry, tourism, and river navigation, are already now vulnerable to water shortages.

Climate change may worsen current water resource issues and lead to increased risk of conflicts between users in the alpine region (particularly the south) but also outside the Alps where droughts are also expected to become more frequent. Observed and projected reductions in permafrost are also expected to increase natural hazards and damage to high altitude infrastructure.

The global climate is forecast to keep changing unless global greenhouse gas emissions are reduced substantially to keep global temperature increases below 2 °C (above pre-industrial levels), which is the EU target. This target is guiding the negotiations on a global post-2012 climate agreement to be discussed at the UNFCCC climate change conference in Copenhagen (December 2009). However, even a global increase of 2 °C will still result in major impacts to which the world and Europe (primarily mountain regions, coastal areas, river floods-prone areas, the Mediterranean and the Arctic) will need to adapt.

The heatwave of summer 2003 demonstrated the potentially severe impacts of higher temperatures and drought on human wellbeing, ecosystems and water-reliant economic sectors (such as power generation). Such extreme events have raised the national and community awareness of the **need to develop adaptation strategies**. Some initial adaptation measures are already in place, partly as a response to extreme events. These initial measures can provide governments and citizens elsewhere guidance on which approaches are likely to be successful and which less so, and also provide a preview of the challenges ahead.

The EU Adaptation White Paper together with the National Adaptation Strategies and the Action Plan on Climate Change of the Alpine Convention provide key steps towards European frameworks for adaptation measures and policies to increase resilience to climate change impacts. The knowledge base, governance structures and implemented actions are important issues to consider for developing effective adaptation measures. Hence, drawing on the most recent knowledge of climate change impacts in the Alps and experiences across the region, this report analyses the risks that climate change presents to the region's water supply and quality, identifying needs, constraints, opportunities, policy levers and options for adaptation. **It extracts policy guidance on adaptation practice and aims to assist regional and local stakeholders in developing robust adaptation strategies. The focus of the report is on water resources and related adaptation**, rather than water-related extreme events like floods, avalanches, landslides or mudflows, which are already well covered by existing studies of climate change impacts in the Alps.

Photo: © European Environment Agency

Regional case studies

The case studies and literature review contained in this report provide valuable insights into the forces that promote or obstruct adaptation and the measures that have proven successful. The key findings are presented below.

Success factors

Political support is a key catalyst for initiating, driving and coordinating adaptation to climate change, providing a strategic framework for effective action. Policies have generally been responses to extreme events or natural hazards that motivate demand for action by public authorities.

Once initiated, adaptation measures rely on a broad variety of factors for their success, relating primarily to institutional and governance structures, as well as organisational settings:

- measures are generally more accepted and successful when they **promote** (or at least do not conflict with) **other goals**, including economic gains. Effective adaptation processes therefore depend a great deal on the people involved and their motivations, as well as organisational factors such as stakeholder participation processes or cooperative structures *(this applies to all case studies to a varying extent)*;

- a **sound legal framework** is a crucial complement to political support. It can provide a clear mandate for establishing cooperation at the water basin, cross-sectoral or inter-regional scale, facilitating sharing of water resources and coordination of water and land users *(see, for example, the case studies on 'River Lavant' and 'Vienna's water mountain' in Austria, the South Tyrol in Italy, Savoy in France and 'River Soča' in Slovenia/Italy)*;

- **technological measures** (e.g. improved irrigation techniques, new reservoirs, rainwater harvesting, wastewater and greywater re-use) play a major part in adaptation measures *(see, for example, the case studies on Valais in Switzerland, the South Tyrol in Italy and Savoy in France)*;

- an increasing number of initiatives consider complementary 'soft' actions on the **demand management side,** such as behavioural adaptation and ensuring full participation and empowerment of stakeholders. By complementing more widespread supply-side technological measures, this strongly supports the resilience and adaptive capacity of the Alps, which is high compared to other mountain areas in Europe due primarily to higher economic resources and a more advanced knowledge base *(see, for example, the case studies on Savoy in France, 'Vienna's water mountain' in Austria and 'River Soča' in Slovenia/Italy)*;

- introducing **market-based economic incentives** (in particular water pricing) and financial support (for example subsidies) is also helpful in encouraging proactive and innovative adaptation measures, ensuring private sector participation and enhancing the success rate of measures taken *(see, for example, the case studies on 'River Lavant' and 'Vienna's water mountain' in Austria, Valais in Switzerland and the South Tyrol in Italy)*;

- **raising stakeholder awareness** about the need for anticipatory adaptation actions is vital, especially in sectors with long lead times (i.e. where long-term investments are needed) such as forestry and power generation. Long term adaptation planning occurs mainly in those sectors, while others plan and act on the basis of shorter timeframes *(see, for example, the case studies on 'River Lavant' and 'Vienna's water mountain' in Austria, Valais in Switzerland and 'River Soča' in Slovenia/Italy)*;

- other **social factors,** in particular local practices and social networks, are also key. For example accepted long-standing adaptation strategies such as complex, traditional irrigation systems, unwritten rules, the effective distribution of responsibilities and existing communication networks, which do not need to be formally institutionalised, decrease conflicts between

Box ES.1 The six regional case studies

The present report contains six case studies that illustrate regional adaptation to key water resource issues resulting from climate change and other causes such as increased water use. In addition to detailed literature analysis for each region, the case studies included interviews with stakeholders who were directly involved in adaptation activities or had knowledge about them. The case studies addressed the Lavant valley and Vienna in Austria, the Valais in Switzerland, South Tyrol in Italy, the Savoy region in France and River Soča in Slovenia and Italy. The key characteristics and issues for each case study are listed below.

River Lavant valley (Austria)
The region has a low level of precipitation and a limited number of springs that can be used for water supply. It has already been affected by water shortages during hot summers. Due to projected climate change impacts, it can be expected that the water resource issues will increase and that further adaptation activities will be essential.

The Valais (Switzerland)
An inner-alpine arid valley, the Valais has always needed to adapt to temporary low water availability. Traditionally, water needed in summer is taken from groundwater or glacial melt run-off, water in winter is taken from reservoirs. Water-related conflicts of interest have been rare. In the future climate change will increase water resource issues because there will be less glacial melt water to compensate for summer drought, with effects on groundwater capacity.

South Tyrol (Italy)
South Tyrol is characterised by dry inner-alpine valleys, where water has been a rare resource for centuries. To address this problem, the South Tyrol has a long history of adapting to water scarcity with a traditional and complex system of irrigation channels, water rights and local water managers. In the last decade, mainly due to a series of dry years combined with increasing demand for water for irrigated agriculture, tourism and households, water scarcity has become a challenge in particular seasons (early spring, high summer) in parts of South Tyrol. While the total amount of water available within the region is sufficient, water scarcity arises from an uneven temporal and spatial distribution of demand and supply.

Savoy (France)
Savoy has a complex topography with many high altitude mountain chains and a wide range of climatic zones, from sub-Mediterranean and oceanic to dry inner-alpine valleys. The available water resources are very variable and, depending on their surface and groundwater storage capacity, are sensitive to climate change and human impacts. Local water supply from springs used to be sufficient for local populations but this supply is now increasingly limited due to expanding communities and the temporary influx of tourists. Thus, water demand problems are exacerbated by a combination of supply limitations and climate change.

Vienna's water mountains (Austria)
The karstic mountains (Mt Hochschwab, Mt Rax, Mt Schneeberg and Mt Schneealpe) play a vital role in supplying water to approximately 2 million people, including the city of Vienna. The main water resource issues in the region arise from the specific geological features (e.g. the short time span between infiltration and discharge of water after an event), from climate change (e.g. rising temperature) and from land use activities (e.g. farming, forestry), which substantially influence water quality. Adaptation activities have been initiated in response to past environmental and socio-economic impacts rather than climate change scenarios. Adaptation to current water problems has been successfully managed so far by the competent authority within the City of Vienna.

River Soča (Slovenia and Italy)
The Soča provides a good example of transboundary river management. The Slovenian part of the Soča river basin is not only one of the wettest parts of Slovenia but also of Europe as a whole. The main focus in this region is on heavy precipitation episodes, related flash floods, debris flow and landslides. Drought is unknown in the Upper Soča valley but in the southern part of the basin drought sometimes occurs due to less precipitation and higher water consumption. Due to projected hotter summers and higher evapotranspiration water supply in the southern part of the basin is expected to decrease while water demand will increase. The Italian representatives to the bilateral Slovenian-Italian Commission in the field of Water Management have already requested more water, especially during periods of drought.

stakeholders and facilitate adequate adaptation responses *(see, for example, the case studies on Valais in Switzerland and 'Vienna's water mountain' in Austria).*

Barriers to adaptation

The case studies and literature review also revealed various barriers to adaptation *(these apply to all case studies to a varying extent)*:

- **limited scientific knowledge and uncertainty** about future climate change's local impacts on water availability, quality and demand is clearly a key barrier to political commitment to anticipatory and forward-looking adaptation measures. This is partly due to huge uncertainties in downscaling climate models and scenarios;

- the **lack of long-term planning strategies, coordination and use of management tools** that consider climate change at regional, river basins and cross-sectoral levels hinders sustainable development of water resources and is a key barrier to effective adaptation. Water supply networks connecting communities or regions can generally cope better with local water shortages and help avoiding uncoordinated actions and individualistic or inefficient solutions;

- **climate change is seldom considered explicitly** in water supply or demand management plans, meaning that water-related adaptation measures responding specifically to current and future climate change impacts are still largely absent. This is partly due to the weak knowledge base on climate change impacts at the local and regional levels. The Water Framework Directive and the River Basin Management Plans (first plans due in 2010) should certainly help integrate and streamline climate change adaptation into sectoral policies.

Potential policy options

The regional case studies and broader empirical research contained in this report generate a variety of insights into developing effective policies for adapting to climate change and water resource issues.

Regional and local adaptation strategies are needed

Stakeholders need to work across municipalities, massifs or river basins/valleys to address climate change impacts and adaptation issues effectively. Regional and local adaptation strategies should as much as possible take into account the characteristics of the local situation (e.g. type and timing of water issues; economic circumstances; ecosystem-related services; drivers of adaptation; and success factors and barriers).

The cross-sectoral nature of water resources and their transboundary interdependence also calls for **multi-level governance and integrated approaches**, which can help coordinate multiple stakeholders from different sectors, regions and policy levels (local, regional, national, EU).

A regional approach to adaptation can significantly help decrease vulnerability, reinforcing local adaptive capacity by delivering adequate institutional and governance structures and combining economic resources. It is appropriate for addressing many climate change-related water resource issues, such as the growing need for inter-communal water transfers or coordination platforms between upstream and downstream localities.

Regional adaptation strategies must guarantee coordinated and efficient exchange of information between different levels of policy-making and stakeholders so that climate change is adequately reflected in policies ('climate proofing'). Some management tools exist that consider climate change (e.g. analytical frameworks, downscaled scenarios, cost-benefit analyses, good practice examples) but are largely unknown among local and regional stakeholders, underlining the high need for dissemination and outreach.

Decisions on current and future climate change adaptation actions at regional and local levels must be taken in conditions of uncertainty. Adaptive management, especially close monitoring, is therefore needed to facilitate regular review of policy objectives and the inclusion of new scientific information that might reduce uncertainty once it becomes available. Climate change adaptation in this respect is not different from any other environmental issue where perfect information and complete scientific knowledge is lacking. The precautionary principle is an appropriate response to knowledge deficits. According to the precautionary principle, the absence of full scientific certainty should not be used as a reason to postpone measures where there is a risk of serious or irreversible harm to public health or the environment. Decision-makers can also take advantage of 'no-regret' measures, i.e. those that would be justified under all plausible climate futures.

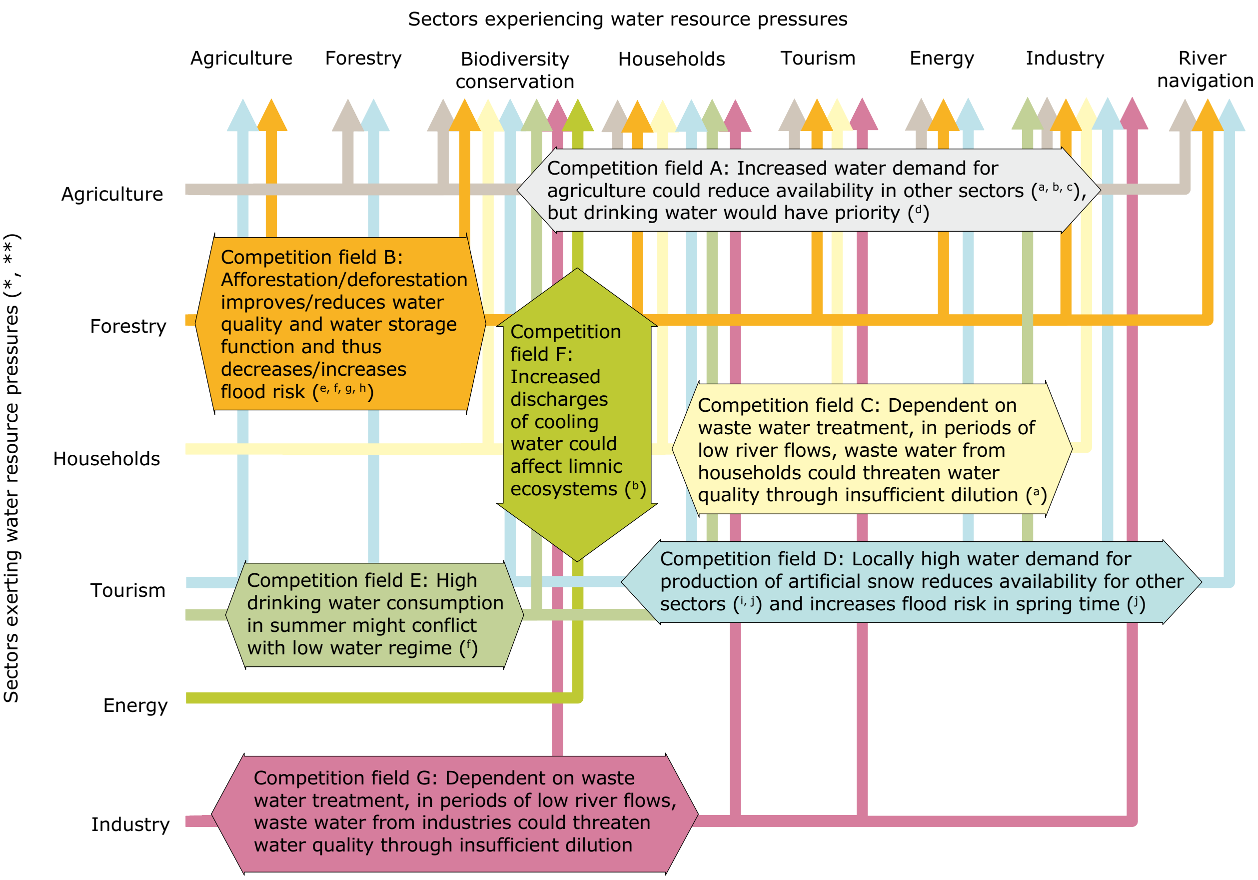
The possibility of non-linear, abrupt or step changes that can alter the state of the environment once a threshold has been reached must also be taken into account in order to **build resilience to cope with the unexpected**.

All sectors need to be considered in adaptation strategies

Water resources are an inherently cross-disciplinary issue, affecting almost all socio-economic sectors. Figure ES.1 illustrates the most important current and expected **cross-sectoral water competition** in the Alps. It differentiates sectors exerting pressures on water resources (with respect to both water quantity and quality) from those experiencing pressures. The main sectors exerting pressure are agriculture, households, tourism and energy production, while the main socio-economic and environmental sectors affected by water resource competition are agriculture, biodiversity conservation, households and energy production.

Integrated management approaches, such as Integrated Water Resource Management, should be used when developing and implementing adaptation measures. They are usually well equipped to take into account the variety of drivers, success factors and barriers to successful adaptation. Integrated approaches require that various elements (e.g. an enabling environment, definition of institutional roles and functions, and the use of management instruments) be integrated consistently

Figure ES.1 Fields of potential cross-sectoral water competition relevant for adaptation



* River navigation is not considered as a sector exerting water resource pressures as it uses but does not consume water.

** Biodiversity conservation is not considered as a sector imposing water resource pressures as it does not actively change water use pattern but rather can be considered as a sector exposed to water competition.

Source: ([a]) OcCC/ProClim, 2007; ([b]) BUWAL and BWG, 2004; ([c]) Oleson *et al.*, 2005; ([d]) Wilibanks *et al.*, 2007; ([e]) IPCC, 2008; ([f]) Leipprand *et al.*, 2007; ([g]) Anderson *et al.*, 2008; ([h]) Giller and O'Holloran, 2004; ([i]) OECD, 2007; ([j]) Teich *et al.*, 2007; ([k]) de Jong, 2008.

and coherently in water resource management. An in-depth assessment of cross-sectoral competition is important to define effective, proportionate and transparent adaptation strategies and options at the regional scale. All strategies should preferably use an ecosystem goods and services framework.

The European Union should provide the overall policy frameworks

The European dimensions of climate change impacts and water resource issues in the Alps are diverse. EU initiatives should provide stakeholders the framework and policy instruments to consider climate change impacts effectively and develop adaptation strategies at national and sub-national levels that address local needs. This will help integrating ('mainstreaming') climate change into policies and streamlining and coordinating adaptation actions across Europe.

Impacts of climate change vary by region, with mountain areas (together with coastal areas and flood plains) particularly vulnerable. This is why most adaptation measures will be carried out nationally, regionally or locally. The European Union should support these efforts through an integrated and coordinated approach, particularly in connection with cross-border and regional solidarity issues, as well as EU policy areas (e.g. common policies, such as agriculture, water, biodiversity, fisheries and energy, and the single market). Climate change adaptation will need to be embedded in all EU policies.

Existing European legislation, particularly the **Water Framework Directive** (WFD), is a good basis for cross-border water coordination and adaptive management. It paves the way towards further integrating climate change adaptation into European policies and implementing adaptation measures, also at a river basin scale where uncoordinated actions should be avoided. Within this context River Basin Management Plans (RBMPs), a key instrument of the WFD (first RBMPs are due in 2010 and the second in 2015), must be coordinated with other sectoral policies (e.g. the Common Agricultural Policy) and secure broad public participation. Economic incentives and demand-side management options also have to be considered further. Guidance on how to include climate change into the RBMPs is being developed (due to be made available in second half of 2009). The Water Framework Directive is complemented by the Floods Directive and the policy on water scarcity and droughts, which provide a more specific framework for adapting to the key water-related impacts of climate change (e.g. droughts management plans, water scarcity and droughts information system).

The EU Adaptation White Paper, published by the European Commission on 1 April 2009, is a key step towards a framework for adaptation measures and policies to strengthen EU resilience to climate change impacts. It stresses the need to develop the knowledge base further and to integrate adaptation into EU policies. The White Paper also prominently recognizes that the impacts of climate change will have varying regional implications, which means that most adaptation measures will need to address local needs.

The EU framework for action presented in the White Paper sets out a two-phase strategy that complements actions taken by Member States through an integrated and coordinated approach. The first phase (until 2012) will be dedicated to preparing a comprehensive EU adaptation strategy from 2013 onwards. The first phase will focus primarily on improving the knowledge base on climate change, possible adaptation measures and means of embedding adaptation in EU policies. An EU Clearinghouse on climate change impacts, vulnerability and adaptation is proposed in the White Paper to be put in place by 2011.

The EU is well placed to facilitate the implementation of the first phase of the framework for action through a series of actions, including:

- supporting **monitoring and data collection networks** to expand the knowledge base and widen the scope for in-depth analysis of long data series. For example, qualitative and quantitative data are still very much needed on water balances, abstraction and its impact on ecosystems, or optimal ecological flow. These data would provide more accurate information, which would enhance transparency for water users and better inform policy-makers;

- developing analytical tools and assessments that report on the adaptive capacity and **vulnerability of natural and human systems**. This will serve the purpose of developing and implementing ecosystem-based adaptation options;

- developing **information platforms** on climate change impacts, risks and adaptation options at the local and regional levels to facilitate information sharing among stakeholders and the dissemination of management tools that consider climate change. Creating such web tools (the proposed EU Clearinghouse) would complement resources available at the national and European levels and help regions, communities and all stakeholders make informed decisions;

- facilitating **exchange of good practices** between Member States to further support capacity-building of regional and local authorities, and encourage those that have not yet prepared national and/or regional adaptation strategies to do so. For instance, so far there has been limited transboundary cooperation in managing water shortages along river basins originating in or fed by the Alpine region;

- fostering **stakeholder participation** in research projects to bridge the gap between scientists, policy-makers and all other relevant parties. Engaging stakeholders more could streamline the flow and sharing of information, and avoid duplication of work and undue delays in taking decisions. This could improve understanding of local knowledge and practices and public awareness, which are essential for successfully implementing adaptation measures, avoiding maladaptation or unsustainable solutions (e.g. artificial snow making).

Under the framework of the **Alpine Convention**, the Alpine Conference adopted an Action Plan on Climate Change in March 2009, aimed at making the Alps an exemplary region in preventing and adapting to climate change. The Action Plan calls for better sharing of information on climate change in the Alps, including good practices in mitigating and adapting to climate change, and on water management to help decision-makers and other stakeholders develop adaptation strategies.

For this purpose a platform on 'Water management in the Alps' will be established. Its mandate is to undertake a survey of water management plans, give guidance on sustainable and balanced use of hydropower and assess the needs for adaptation to climate change. In addition, the *Second Report on the State of the Alps* with focus on water and water management issues, published in 2009, dedicates a specific chapter to climate change and water management.

Adaptation experiences are not easily transferrable to other mountain regions

Local and regional situations differ considerably both within the Alps and by comparison with other European mountain regions. That means significant variance in demography, climate and environmental impacts, economic structures, cultures and values, land uses (urban, agriculture, pasture), and patterns of public and private partnerships. These local conditions make it challenging to transfer lessons learned from the regional case studies and other information sources to other areas within the Alps or to other European mountain regions as a whole.

Nonetheless, many lessons learnt from adaptation in the Alps are of a **generic nature** and practical experience in the Alps provides guidance for designing regional strategies to adapt to climate change impacts and water resource issues. As noted above, key elements of successful strategies include tailoring measures to specific regional climate conditions, affected sectors and political and socio-economic contexts; ensuring dialogue between stakeholders through cooperative structures and knowledge transfers; and monitoring progress to support regular reviews of policy objectives and the inclusion of new scientific information when becoming available. These elements would help deliver water resource management that takes climate change into account more systematically and follows a proactive, precautionary and cross-sectoral approach.

Setting the scene

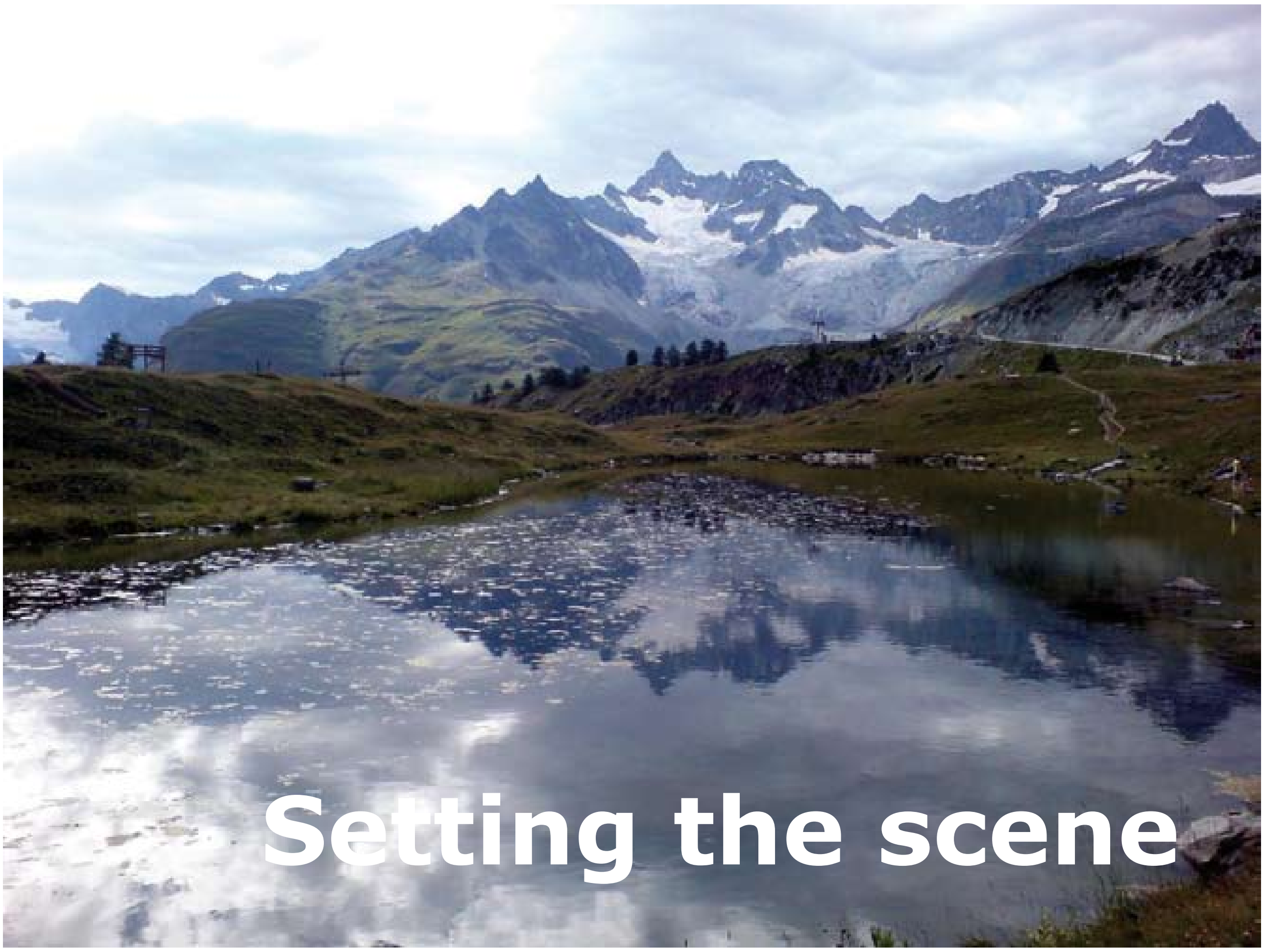


Photo: © Torsten Grothmann

1 Introduction and overview

1.1 The Alps — a highly vulnerable region and the water towers of Europe

The EU White Paper on Adaptation (EC, 2009) names mountain areas, in particular the Alps, as among the most vulnerable areas to climate change in Europe. The Alps have undergone an exceptionally high temperature increase of around + 2 °C between the late 19th and early 21st century, more than twice the rate of average warming of the Northern hemisphere, leading to widespread melting of glaciers, climbing of the snowline, changes in the run-off regime of rivers and general water resources availability (Auer *et al.*, 2007).

The Alps are responsible for a disproportionately high contribution to the total discharge of the four major rivers — mainly Danube, Rhine, Po and Rhone — flowing from the region, from 26 % (Danube) to 53 % (Po) (Weingartner *et al.*, 2007). Most of the major European rivers have their headwaters in the Alps and their discharge is transported via river systems to lower-lying areas. The Alps are crucial for water accumulation and water supply and therefore they are often referred to as natural 'water towers' (Viviroli and Weingartner, 2004). Hence, the water system of the Alps is very important not only for the countries in the Alps but also for large parts of Europe.

In the future, the combined effects of droughts and increased water consumption in the Alps could cause water supply problems throughout Europe. Future climate change is projected to lead to a shift from summer precipitation to winter precipitation. Together with an earlier and reduced snow melt due to lower storage of winter precipitation as snow as well as less glacial melt water this will lead to an essential decrease in summer run-off all over the Alps (see Chapters 2 and 3).

A decrease in water availability has severe impacts on all sectors relying on water, amongst them agriculture (irrigation, particularly in the southern Alps), hydropower production, industry, households, winter tourism (for example snow-making) and river navigation. Due to the sensitivity of these sectors, the vulnerability of the Alps in the absence of further adaptation has been rated as 'high' (Zebisch *et al.*, 2005).

1.2 Study objectives and regional focus

This study focuses on the impacts of climate change on water resources. It provides an added value compared to the recent OECD study *Climate change in the European Alps* (OECD, 2007). The OECD study focuses on winter tourism and natural hazards management (including extreme events and floods), but only marginally addresses the issues of water supply, water scarcity and water quality as impacts of climate change.

This study puts emphasis on the need to implement a strong and effective stakeholder dialogue in order to link the European Environment Agency (EEA) with regions. It focuses especially on those tasks mentioned by the European Commission's White Paper on Adaptation (EC, 2009) as necessary for practical implementation of adaptation action.

To guarantee the study's regional impact a project consortium was built consisting of partners with a strong link to the Alps: the Environmental Protection Agencies of Austria (UBA Vienna) and Germany (UBA Dessau), Accademia Europea di Bolzano (EURAC, Italy), Potsdam Institute for Climate Impact Research (PIK, Germany) as members of a project consortium in EEA's European Topic Centre on Air and Climate Change (ETC/ACC); the Environmental Protection Agency of Slovenia (Ljubljana), Eidg. Forschungsanstalt für Wald, Schnee und Landschaft (WSL, Switzerland), Institut de la Montagne (France), Zentralanstalt für Meteorologie und Geodynamik (ZAMG, Austria), Ministero dell'Ambiente e della Tutela del Territorio e del Mare (Italy), University of Geneva (Switzerland) as contributing partners; and the Permanent Secretariat of the Alpine Convention (Innsbruck/Bolzano) as associated partner. The study was financed by the EEA, UBA Dessau and UBA Vienna.

The objectives of the study are:

- to gain some insights into the vulnerability of the Alps and surrounding European regions with regard to the impacts of climate change on water resources and specific water-sensitive regions in the Alps;

- to assess possible needs, constraints and opportunities for adaptation to the adverse impacts of climate change on water resources;
- to support regional and local administrations in making informed decisions to better develop and implement adaptation strategies;
- to assist the Parties of the Alpine Convention to improve their understanding and assessment of impacts, vulnerability and adaptation, and to make informed decisions on practical adaptation actions;
- to raise awareness and share information about existing methods and tools for assessing impacts of climate change and developing adaptation strategies;
- to support networking on adaptation actions between stakeholders, science and administrations; and
- to increase the cooperation between the EEA, regional decision-makers and the Alpine Convention.

The EEA chose water resources in the Alps as a focal issue for the following reasons:

1 The Alps and particularly the water sector are vulnerable to climate change due to an above-average temperature increase in the Alps and decreasing summer run-off due to decreasing snow and glacier cover;

2 Water availability in, and supply from, the Alps have a major role to play in water management not only within the Alps but also for large parts of Europe (the Alps as water towers of Europe). Therefore, this issue represents a regional topic with a European dimension — calling for multilevel governance approaches and adaptation strategies;

3 Water availability is a trans-disciplinary issue that affects almost all socio-economic sectors — calling for integrative cross-sectoral approaches and adaptation strategies.

Until now no reports on the impacts of climate change on the water resources of the European Alps have included specific stakeholder-oriented information on strategies to adapt to these impacts. This report analyses climate change impacts on water availability, water quality and droughts and extensively discusses strategies to adapt to these impacts. Other water-related natural hazards like floods, avalanches or mass movements (landslides or mudflows) are beyond the scope of this study. They are already well covered by existing publications on climate change impacts in the Alps. For example, the Climate Change, Impacts and Adaptation Strategies in the Alpine Space (ClimChAlp) project (for example, ClimChAlp, 2008) extensively studied natural hazards, the Organization for Economic and Social Development (OECD) study (OECD, 2007) addressed natural hazards and winter tourism. A first *Report on the state of the Alps* (RSA I) with a focus on transport was published in 2007 (Alpine Convention, 2007). The second *Report on the state of the Alps* (RSA II) with its focus on water and water management issues in the Alps is discussed in Section 1.3.

During the last few years the EEA has published several reports on climate change and water issues: for example Climate change and water adaptation issues (EEA, 2007), Impacts of Europe's changing climate — 2008 indicator-based assessment (EEA, 2008) and Water resources across Europe — confronting water scarcity and drought (EEA, 2009). This EEA Report *Regional climate change and adaptation — The Alps facing the challenge of changing water resources* is one of several ongoing activities to assess the risks of climate change for mountain areas. The Conference of the Parties to the Convention on Biological Diversity decided at its ninth meeting in Bonn (19–30 May 2008) to prepare a report by 2010 providing species occurrence data, an analysis of risks from climate change for existing protected areas in mountain regions and information to reduce impacts of climate change on small protected areas (CBD, 2008). In October 2008 the Assessing Climate impacts on the Quantity and quality of WAter (ACQWA) Project started. The objectives of this integrated, large-scale project, with 35 partners and a budget of 6.5 million EUR, are 'to assess the impacts of a changing climate on the hydrologic cycle in mountain regions, focusing on the quantity and quality of water' (ACQWA, 2009).

1.3 EU policy background

Decision-makers and stakeholders at European, national, federal, regional and local levels express a high interest in information on climate change impacts and adaptation in the Alps, especially with regard to water availability. Also, the Permanent Secretariat of the Alpine Convention expresses a high interest in a study on climate change impacts and adaptation in the Alps.

The Alpine Convention is a multilateral framework treaty for the protection and sustainable development of the alpine region. The contracting parties to the Alpine Convention consider climate policy and the development of adaptation strategies for the Alps to be a priority of cooperation. During the IXth session of the Alpine Conference, held in Alpbach (Austria) in 2006, a declaration on climate change in the Alps was adopted calling for concerted action of the eight countries in the Alps to combat climate change by mitigation and adaptation measures (Alpine Convention, 2006). The conference also asked the French presidency of the Alpine Convention to draft an Action Plan on Climate Change aimed at making the Alps an exemplary region in the prevention of and adaptation to climate change. The Action Plan on Climate Change of the Alpine Convention will be implemented with the support of the Permanent Secretariat of the Convention, which has been asked to install an Internet platform with relevant and current information on climate change in the Alps, including good practice in mitigation and adaptation to climate change. The Xth Alpine Conference in Evian (March 2009) decided in addition to install a platform on 'Water management in the Alps' under Austrian–Swiss Co-Presidency. The platform will work until the XIth Conference according to the decided mandate with special focus on doing a survey of the relevant water management plans in the alpine region, developing recommendations for sustainable and balanced use of hydropower in the alpine area and assessing the developments with regard to the need for adaptation to climate change as well as some additional tasks. In addition, the second *Report on the State of the Alps* (RSA II), adopted during the Xth Alpine Conference, addresses the subject of water in the Alps and dedicates a specific chapter to climate change and water management. Members of this report's project consortium were invited to attend the conference and regularly participated at the working group meetings of the RSA II in order to align the two reporting activities and correlate assessments. The Permanent Secretariat of the Alpine Convention was the main contact point for both activities. Compared to the RSA II, this EEA report includes a more detailed analysis of potential climate change impacts and advisable adaptation measures.

This report also responds to the European Commission's White Paper *Adapting to climate change: Towards a European framework for action* (EC, 2009) in particular to the

- 1st pillar on 'Building a solid knowledge base on the impact and consequences of climate change for the EU', which includes the requirement to 'share the knowledge across member states', by providing an overview of existing knowledge on potential impacts of climate change on water resources in the Alps;

- 2nd pillar on 'Integrating adaptation into EU key policy areas', such as the water sector, which stresses the need for coordinated and comprehensive adaptation strategies outlining the types of action needed, by summarising existing and potential adaptation strategies and by identifying gaps and needs for further development; and to the

- 4th pillar on 'Stepping up international cooperation on adaptation', which calls for the mainstreaming of adaptation in all of the EU's external policies, by giving recommendations on adaptation to water resource issues in mountain regions and transboundary settings.

In addition, the report specifically supplies information for, and relates, to the following aspects of the EU Water Framework Directive (WFD):

- since the WFD provides a consistent framework for integrated water resource management (IWRM) in the EU, it is also a legal framework for the EU member states of the Alps to deal with water problems arising from climate change. As yet, the main text of the WFD does not explicitly address climate change. Nevertheless, 'it is well-suited to handle the long-term implications of climate change with its step-wise and cyclical approach' (EEA, 2007). This report addresses the challenges of such an adaptive management approach by developing elements of a proactive, precautionary, long-term, integrative, participatory and adaptive water resource management approach (stressing the role of IWRM, monitoring, management under uncertainty and stakeholder dialogue);

- the WFD addresses driving forces and pressures affecting the water resources, which are often related to various sectors like hydropower or agriculture. This report assesses these driving forces and pressures in relation to climate change following an ecosystem services approach. In addition, the role and problems of cross-sectoral coordination are specifically addressed.

This report identifies and highlights the needs for action in this highly sensitive and dynamic field of EU water management. It is addressed to public and private stakeholders and decision-makers in water and environmental-related issues, not only in countries of the Alps but across the whole EU at local, regional, federal, national and European levels.

1.4 Theory and concepts

One of the main objectives of this study on climate change impacts and adaptation in the European Alps is to gain some insights into the vulnerability of the Alps and surrounding regions with regard to the impacts of climate change on water resources and specific water-sensitive regions in the Alps. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes' (Parry *et al.*, 2007). In the context of this study, we focus on the adverse effects of climate change, climate variability and extremes on water resources, including problems of water scarcity and water quality. In addition, we explicitly address stresses other than climate change (for example water use).

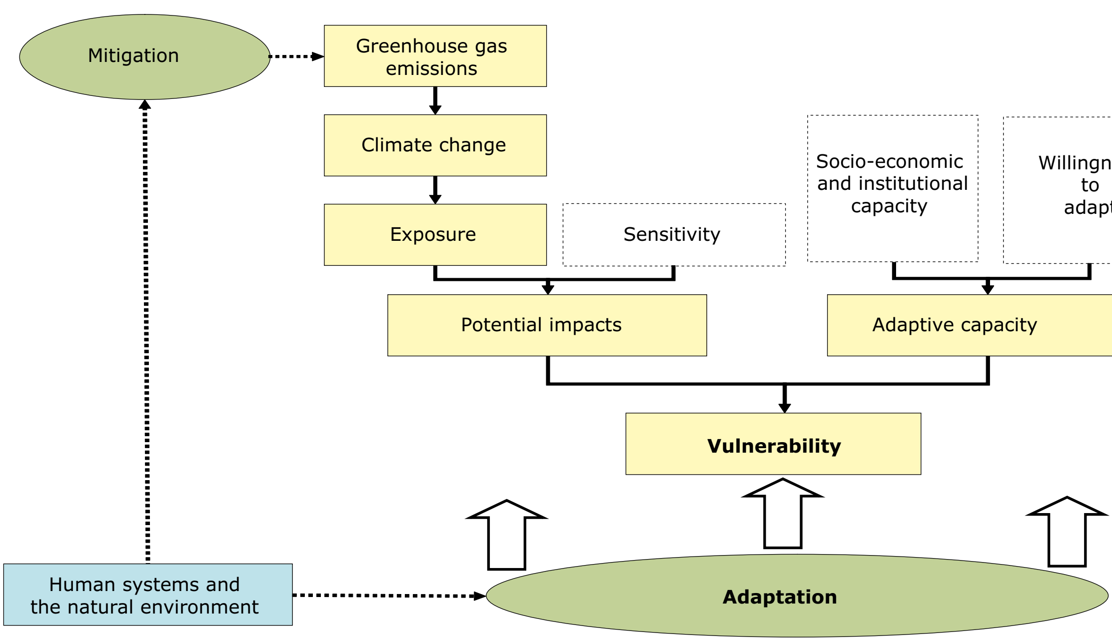
As one of the most important determinants of vulnerability, our study focuses on adaptation —'adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (Adger *et al.*, 2007). Adaptation can reduce vulnerability and depends on the adaptive capacity of a social system, and therefore on the institutional and economic capacity as well as the willingness to adapt (Grothmann and Patt, 2005). This study examines adaptation to water resource issues rather than adaptation to climate change in general.

Figure 1.1 shows the interrelation between climate change impacts, adaptive capacity, vulnerability and adaptation to climate change as a conceptual model to help understand the methodological approach of this study.

1.5 Structure and methodology of study

The first part of the report 'Setting the scene' is based on an extensive review of literature and projects on climate change in the Alps (Chapter 2), climate change impacts on alpine river catchments (Chapter 3) and different water-sensitive sectors (Chapter 4). In addition, several expert interviews were conducted to gain knowledge, especially on as yet unpublished project results.

Figure 1.1 Conceptual model for climate change impacts, vulnerability and adaptation



Source: EEA, 2008; Isoard, Grothmann and Zebisch, 2008.

The second part of the report 'Case studies' (Chapter 5) presents the results of the analysis of activities to adapt to water resource issues in various regions of the Alps. We focused on regions that are already or in the future may be specifically exposed to such issues (shortages, quality), and in which adaptation activities have already been carried out or are planned. The case studies were carried out for the Lavant valley (Austria), the Valais (Switzerland), South Tyrol (Italy), the Savoy region (France), an alpine region essential for Vienna's drinking water supply (Austria) and the River Soča (Slovenia). The case studies were based on detailed literature analyses for the different regions and, importantly, interviews with stakeholders who were directly involved in the adaptation activities or had knowledge about them. The methodology of the case studies (including the criteria for their selection and the interview procedure) is described in more detail at the beginning of Chapter 5.

The third part of the report, 'Lessons learnt' (Chapters 6 and 7), assesses the outcome of the case studies, draws a methodological framework for adaptation based also on the larger literature on climate change adaptation and water resource management and points to possible future developments. The 'Lessons learnt' section is based partly on a workshop involving experts on climate change impacts, water resource issues and water governance that took place on 23/24 October 2008, in Bolzano (Italy). The experts discussed the results of the different case studies and identified what lessons can be learnt for processes of adaptation to climate change and water resource issues. Chapter 6 describes lessons learnt and contains recommendations for adaptation on a regional scale. This chapter specifically addresses the needs and interests of local and regional decision-makers in the Alps facing the challenge of adapting to water scarcity and climate change. Chapter 7 suggests transboundary adaptation and river management strategies to tackle the significant problems associated with the major role of alpine water for water availability not only within the Alps but also for large parts of Europe. Therefore, the chapter specifically addresses the needs and interests of national and European decision-makers. Finally, lessons learnt for other European mountain regions are analysed. This addresses the interests of decision-makers in other mountain regions in Europe and discusses which results of this study on water resource issues and adaptation in the Alps can be transferred to other European mountain regions.

2 Climate change in the Alps

Key messages

The Alps have undergone an exceptionally high temperature increase of around + 2 °C between the late 19th and early 21st century, more than twice the rate of average warming of the Northern hemisphere. Furthermore, a slight trend towards an increase in precipitation in the north alpine region and a decrease in the south has been recorded.

Regional climate models project continuously rising temperatures for the Alps up until the end of the 21st century (between + 2.6 °C and + 3.9 °C), with an accelerated increase in the second half of the century. Changes in precipitation are moderate in terms of the yearly total, but show significant changes within the seasons, mainly a decrease in summer precipitation and, in most regions, an increase in spring and winter precipitation. Precipitation in winter will increasingly fall as rain rather than snow, leading to fewer days with snow cover. Corresponding with these changes in precipitation and snow cover, increase in winter run-off and decrease in summer run-off will be enhanced.

2.1 A brief view of the alpine climate over the past 250 years

Global warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Global mean surface temperatures have risen by 0.74 °C ± 0.18 °C when estimated by a linear trend over the last 100 years (1906–2005). Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (IPCC, 2007).

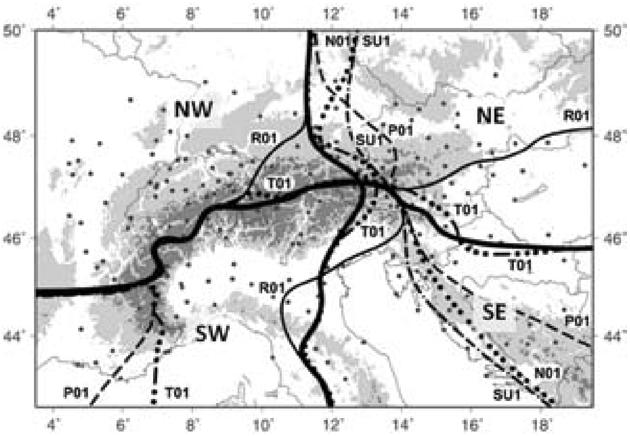
During the 20th century most of Europe also experienced increases in average annual surface temperature (average increase over the continent 0.8 °C), with stronger warming over most regions in winter than in summer (Alcamo *et al.*, 2007).

Recent observations confirm that the global mean temperature has increased by 0.8 °C compared with pre-industrial times for land and oceans, and by 1.0 °C for land alone (EEA, 2008). Europe has warmed more than the global average (1.0 and 1.2 °C, respectively), especially in the south-west, the north-east and mountain areas. Climate change therefore makes European mountains especially vulnerable. Observed and projected impacts include the following: changes in the hydrological cycle of mountain regions and the changing water availability in elevated and surrounding regions; decline in snow and glacier cover; reduction in permafrost increasing natural hazards and damage to high-mountain infrastructure; northward and uphill distribution shifts of many European plant species (60 % of mountain plant species may face extinction by 2100) and reduction in the attractiveness of major tourist resorts.

Climate change in the Alps over the past 250 years has been extensively studied by the project HISTALP (Auer *et al.*, 2007). The HISTALP database contains monthly homogenised records of temperature, pressure, precipitation, sunshine and cloudiness for time series dating back to 1760 for temperature and to 1800 for precipitation for the Greater Alpine Region (GAR), (Figure 2.1). Within the GAR, four horizontal climate regions have been identified — north-west, north-east, south-west and south-east — and one additional region in the vertical sense, which is composed of an altitudinal zone higher than 1 500 m.

Climate variability and climate change is closely related to the long-term warming trend visible in the seasonal and annual mean temperature time series of GAR (see Figure 2.2). Figure 2.2 shows the regional averages of half-year temperatures from 1760 (1760/1761) to 2007 (2007/2008) along with the annual range (summer minus winter half-years) of temperature.

Figure 2.1 Leading horizontal climate sub-regions of the Greater Alpine Region (GAR)



Note: Bold lines: north-west (NW), north-east (NE), south-west (SW) and south-east (SE). Thin lines: sub-regions for single climate elements (P01 air pressure, T01 air temperature, R01 precipitation, SU1 sunshine, N01 cloudiness).

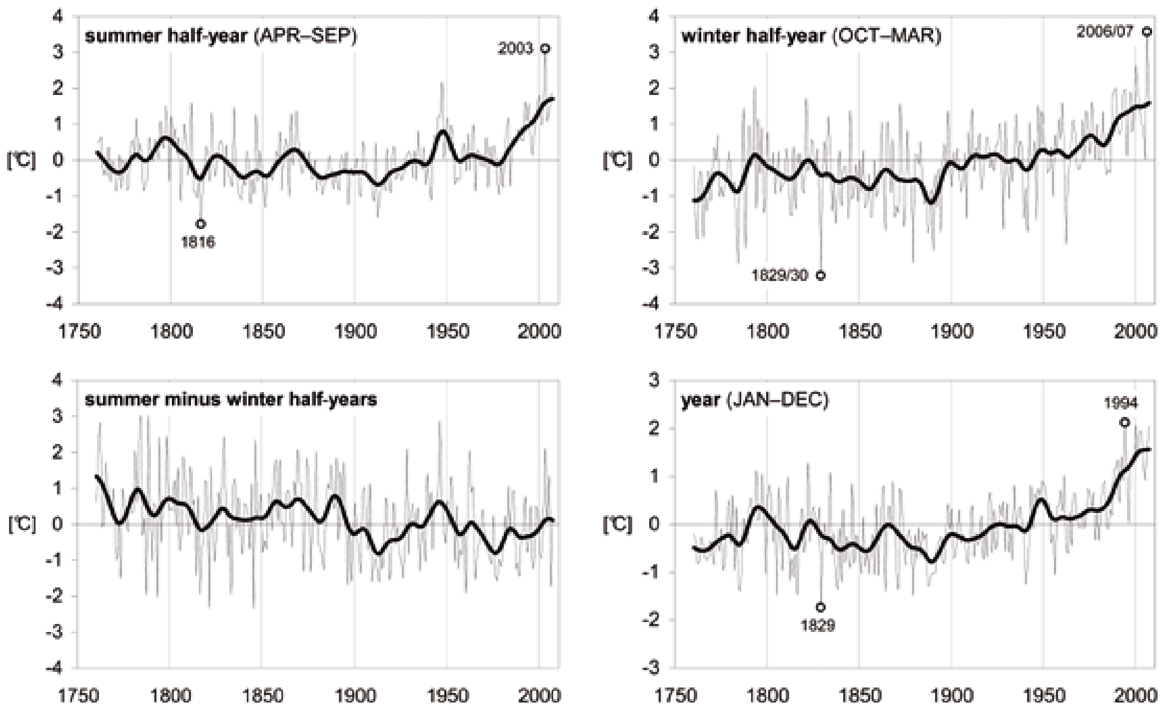
Source: For details, see Auer *et al.*, 2007.

The figure demonstrates an overall annual temperature increase of about 2 °C from the late 19th century up until the early 21st century. The increase took place in two surges after a decrease of 1 °C from 1790 to 1890. The 'stepped' process of warming over the 20th century was more accentuated in summer than in winter. Winters do not show the pronounced summer cooling phase from the 1950s to the 1970s either, which was nearly 1 °C in magnitude.

Inter-annual variability is higher in the cold season, but not stable in all sub-regions. In the Mediterranean area (not shown) winter and summer half-years exhibit equal variance. The annual temperature range, represented by the summer (minus winter) half-year differences, is shown in the lower right graph of Figure 2.2.

There is a significant change from a stronger annual cycle before 1900 to a weaker one in the 20th century. Smallest summer–winter differences occurred in the 1910s and from the 1960s up until the 1970s. These two (oceanic) phases typically went along with the

Figure 2.2 Change in temperature 1760–2007 for the Greater Alpine Region (GAR) Single years and 20-year smoothed mean GAR series from 1760–2007 (1760/1961–2007/2008)



Note: Single years (thin lines) and 20-year smoothed mean (bold lines). All relative to 1851–2000 average, summer and winter half-years (first row), annual mean and annual range (second row).

Source: ZAMG-HISTALP database (version 2008, including the recent EI correction (EI = early instrumental period) described in Böhm *et al.*, 2008).

last two glacier advances in the Alps, which were triggered by cool summers with higher albedo (reflectance of radiation) due to more frequent snow cover on the glacier surface.

During the last 25 years winters and summers have warmed at comparable rates, which is not typical for the regional climate evolution over the past 250 years. This has caused the extraordinary increase of the annual mean temperature by 1.2 °C/25 years (lower right panel) which is unprecedented throughout the instrumental period.

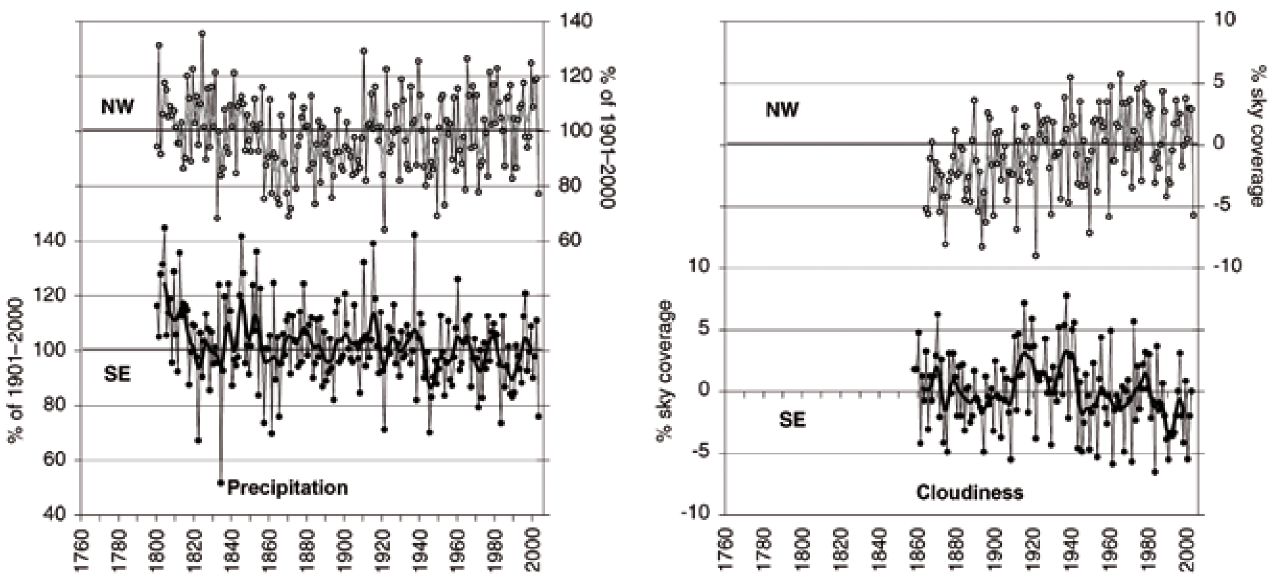
Within the Alps there are no sub-regional differences — the highest mountain observatories such as Sonnblick, Zugspitze or Jungfraujoch, show exactly the same trends as Munich, Vienna, Milano, Marseille or Sarajevo. The shorter (only back to the 1850s) global mean temperature series (not shown here, compare for example Jones and Moberg, 2003) show similar decadal scale features, but only half of the long-term warming of the Alps since the mid-19th century.

The stronger regional warming has been caused by a systematic northward shift of the global subtropical high pressure bands. The increased mean air pressure in the region (Auer *et al.*, 2007) has significantly extended sunshine duration in the Alps. Along with a general decrease of wind speed in central Europe during the 20th century (Matulla *et al.*, 2007), this has resulted in a climate more influenced by local forces, strongly controlled by incoming solar radiation rather than by the global mean evolution, where local to regional circulation changes play no part.

The current body of knowledge assumes that since the mid-20th century anthropogenic interference (increased tropospheric aerosols [cooling] and greenhouse gases [warming]) has become comparable in magnitude to natural forces (mainly solar, natural greenhouse gases, stratospheric aerosols). This has primarily caused a slight cooling from the 1950s to the 1970s (when anthropogenic aerosols took control) and a subsequent pronounced warming (when greenhouse gases became more important). The pre-1950 temperature curves can nearly exclusively be attributed to natural climate forces.

Further studies show that trends in climate parameters other than temperature do not follow the same pattern. Auer *et al.* (2005) analysed precipitation and detected two antagonistic centennial precipitation trends: a wetting trend (since the 1860s) in the north-west of the Alps (eastern France, northern Switzerland, southern Germany and western Austria) and a drying trend (since 1800) in the south-east (Slovenia, Croatia, Hungary, south-eastern Austria and Bosnia-Herzegovina). Figure 2.3 shows this for annual precipitation in the NW and SE, together with the subsequent (but shorter) sub-regional

Figure 2.3 Annual precipitation series (left graph) and annual cloudiness series (right graph)



Note: NW (top, grey) vs SE (bottom, black). All values relative to the 1901–2000 averages. Single years (thin lines) and 10-years smoothed (bold lines).

Source: ZAMG-HISTALP database (Auer *et al.*, 2007).

cloudiness series. Other studies (for example, Schmidli *et al.*, 2002) confirm these findings.

Analysing the past climate is an essential and indispensable precondition for understanding the future climate. Climate models have to reproduce records of past climate before they can be trusted to meaningfully predict future developments. Hence, climate model results ought to be compared to the range of natural and partially anthropogenic climate variability of the past.

2.2 Future climate change

2.2.1 Modelling climate change and global climate scenarios

Future climate cannot be predicted. Instead, climate researchers make use of scenarios. Climate scenarios are plausible descriptions of how climate may change in the future, mainly depending on assumptions of future greenhouse gas emissions. The IPCC uses four different narrative story lines, or scenario families (A1, A2, B1, B2) to describe consistently the relationships between emission driving forces and their evolution (Nakićenović and Swart, 2000). Two moderate scenarios (moderate high: A1B, moderate low: B1) have been considered in this report in order to illustrate a quite realistic range of possible future developments:

- The A1 story line and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1B scenarios used in this report assumes a balanced use of energy sources that does not rely on fossil fuels alone. Compared to other more extreme scenarios of the A family, A1B represents a moderate increase in greenhouse gas concentration in the atmosphere.

- The B1 story line and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 story line, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. B1 represents a moderate low emission scenario.

Scenarios of future climate change obtained from global climate models (GCMs — general circulation

Photo: © Torsten Grothmann

models) project a further rise in global temperature by + 1.8 °C to + 4.0 °C (Meehl *et al.*, 2007)

In Europe, the annual average temperature is projected to rise this century by 1.0–5.5 °C (best estimate), with the largest warming over eastern and northern Europe in winter, and over south-western and Mediterranean Europe in summer (EEA, 2008).

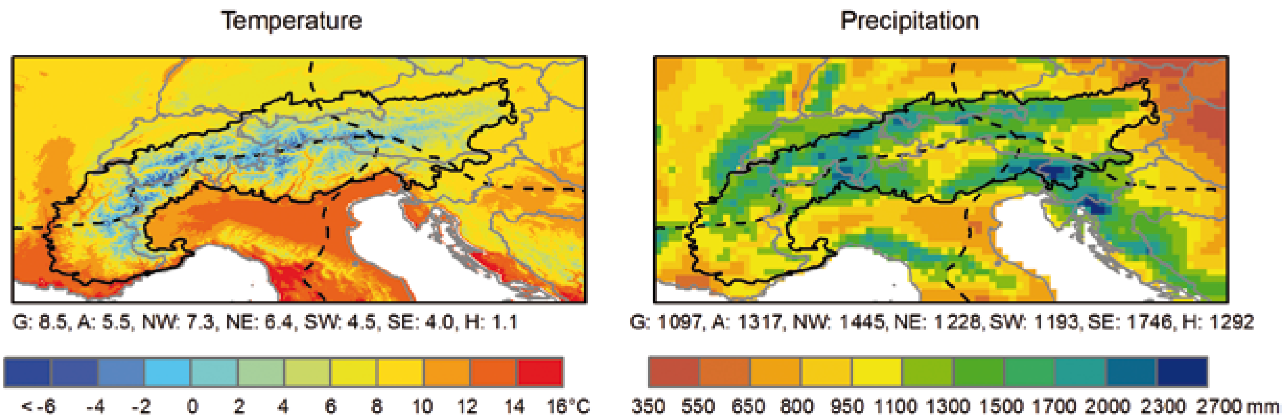
2.2.2 Climate change scenarios for the Alps

While global climate models can give a very consistent picture of general circulation patterns and changes, they are much too coarse in resolution for regional applications. Regional climate models (RCMs) fill this gap by considering such processes and allow the downscale of results from GCMs to a 10–50 km resolution.

For this report we use largely the results from two Regional Climate Models (RCMs) for the A1B and the B1 scenarios that cover the Alps at very high resolution and show a good representation of the orographic (terrain) situation of the region.

CLM (climate version of the local model) is an RCM developed by the CLM community, based on the local

Figure 2.4 Temperature and precipitation in the Alps for the period 1961–1990



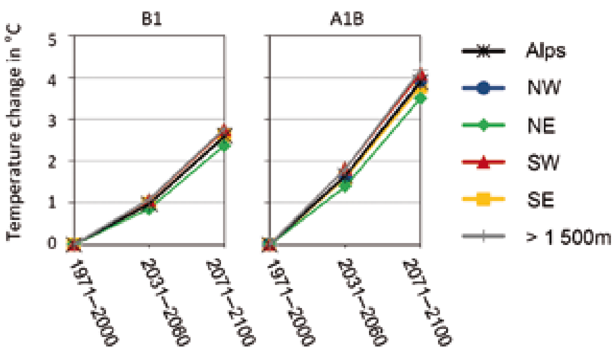
Note: Regional statistics: G = Greater Alpine Region, A = Alps, NW = north-western Alps, NE = north-eastern Alps, SW = south-western Alps, SE = south-eastern Alps, H = higher than 1 500 m.

Source: Data for temperature, Auer *et al.* (2008); data for precipitation, Efthymiadis *et al.* (2006).

model (LM) for an operational weather forecast of the German weather service (DWD). For this report, runs from Lautenschalger *et al.* (2008) were used for the simulation of the past (1960–2000) and the future scenarios A1B and B1 (2000–2100). The results have a resolution of 0.2 degrees (~ 20 x 20 km) and cover the whole of Europe.

REMO (regional model, Jacob, 2001) is an RCM developed by the Max Planck Institute in Hamburg. The results used here are provided by scenario runs for Germany, Austria and Switzerland, financed by the German Environmental Agency (UBA). REMO was run at about 10 x 10 km horizontal resolution for the time period of 1950–2100.

Figure 2.5 Temperature change in the Alps and their sub-regions according to different emission scenarios



Note: Regional statistics: G = Greater Alpine Region, A = Alps, NW = north-western Alps, NE = north-eastern Alps, SW = south-western Alps, SE = south-eastern Alps, H = higher than 1 500 m.

Source: EURAC, 2008, based on data from CLM climate scenarios (Lautenschalger *et al.*, 2008).

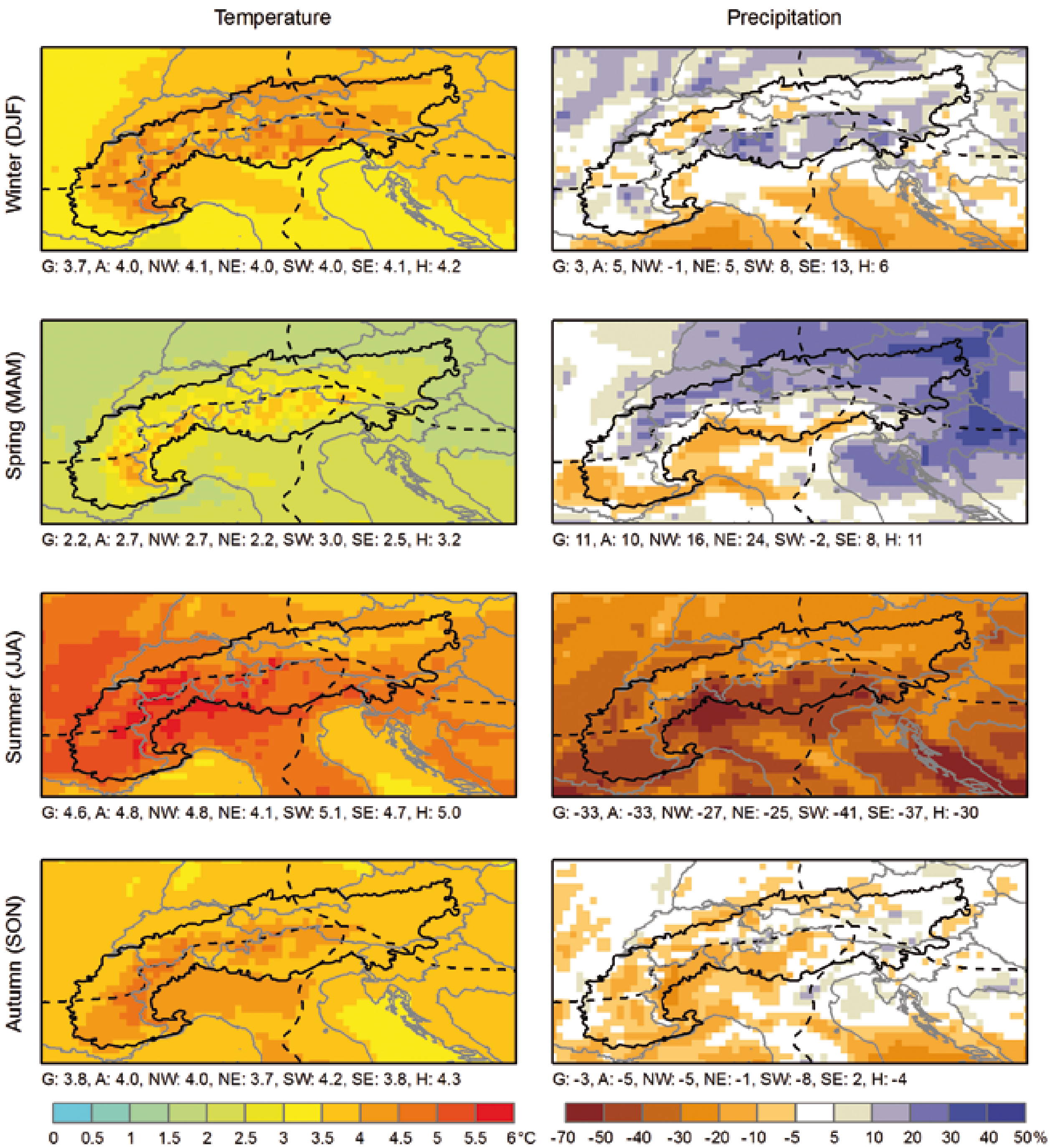
For both models, absolute and relative differences from the reference period (1970–2000) and for two future periods (2031–2060; 2071–2100) were calculated. Since the REMO data do not cover all of the Alps, only CLM data was used to produce maps. For the maps, further statistics were calculated for a) the Greater Alpine Region (GAR), b) the Alps, according to the Alpine Convention and c) the four alpine climate regions (NW, NE, SW, SE) within the Alps and d) areas higher than 1 500 m (Figure 2.1).

The following section will give a more detailed picture of changes, focusing on CLM data, since only CLM covers the Alps fully.

2.2.3 *Temperature*

Today, temperatures in the Alps follow a clear altitudinal gradient (Figure 2.4). Average yearly temperatures range from – 6 °C in the high Alps to almost 14 °C in the southern foothills. As in the past, the Alps will be exposed to a stronger warming than the rest of Europe. According to the CLM A1B scenario, a temperature rise of 3.9 °C up until the end of the 21st century is projected for the Alps, compared with a warming of 3.3 °C for Europe as a whole. The warming will be particularly elevated in the high mountains (> 1 500 m), with a 4.2 °C increase. Until the mid-21st century the temperature increase will be comparatively low (1.4 °C). This means that the warming in the second half of the 21st century will be much faster, with an additional 2.1 °C increase (Figure 2.5). Temperature increase would be significantly lower under the lower greenhouse gas concentration scenario CLM B1, with a projected + 2.6 °C up until the end of the century.

Figure 2.6 Seasonal changes in precipitation and temperature up until the end of the 21st century, according to CLM scenario A1B



Note: Left: absolute difference in temperature. Right: relative difference in precipitation. Regional statistics: G = Greater Alpine Region, A = Alps, NW = north-western Alps, NE = north-eastern Alps, SW = south-western Alps, SE = south-eastern Alps, H = higher than 1 500 m. Seasons are: Winter (December, January, February) Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November).

Source: EURAC, 2008, based on data from CLM climate scenarios (Lautenschalger *et al.*, 2008).

Future temperature increase varies significantly between the seasons. The highest increase is expected in summer with an average of + 4.8 °C (Figure 2.6), some grid cells in the highest regions of the Alps even exceed + 6 °C. The lowest temperature increase in the Alps is expected for spring (+ 2.7 °C). The south-west is exposed to the highest temperature increase (yearly average 4.1 °C) and the north-east the lowest (3.5 °C). The north-west and south-east lie in between, with 3.9 °C and 3.8 °C respectively.

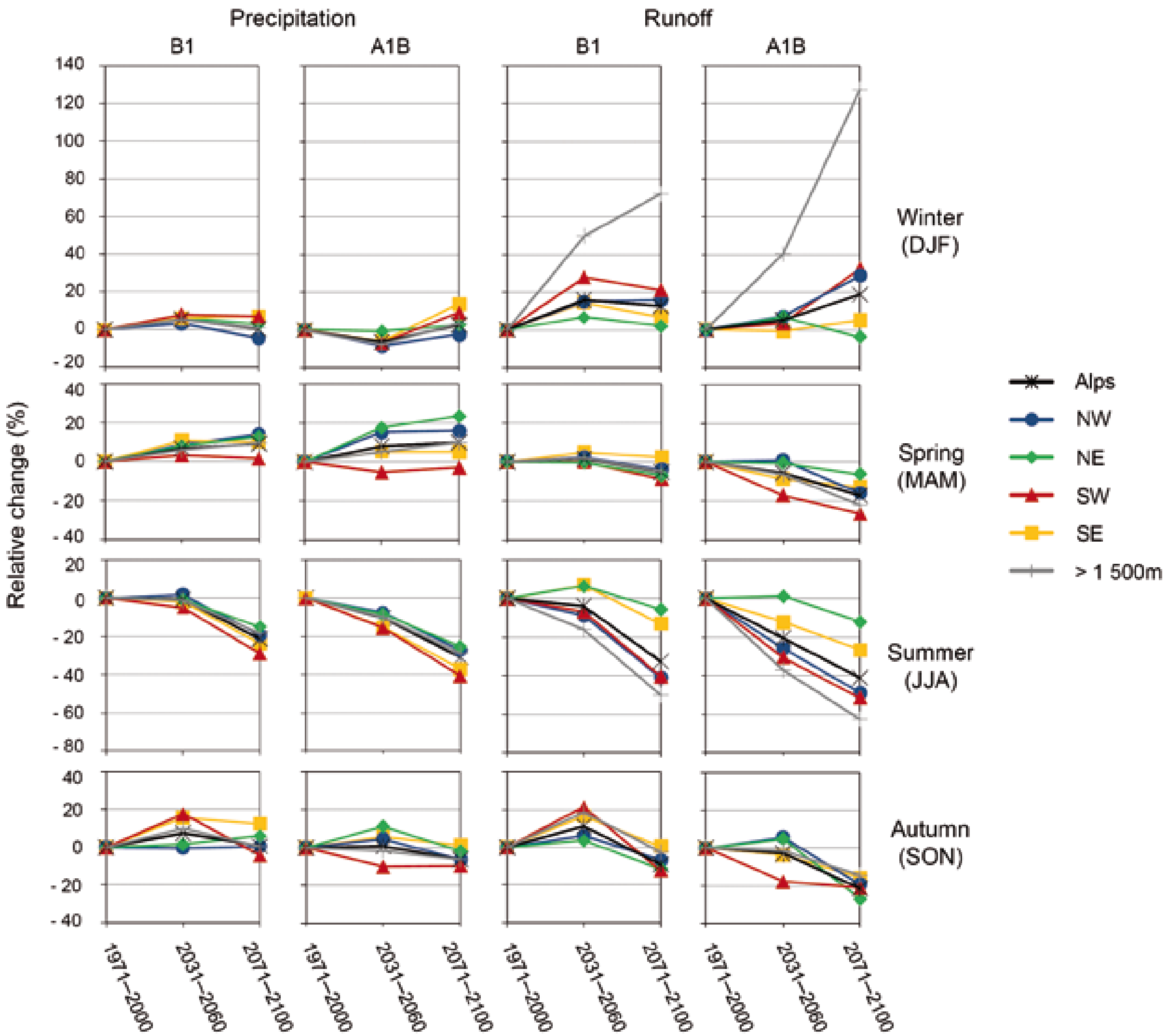
2.2.4 *Precipitation*

The recent spatial pattern of total annual precipitation in the Alps varies greatly from region to region (Figure 2.4). Precipitation is high in the north-eastern, north-western and south-western Alps (1 500–2 700 mm/year), but comparatively low in the dry regions of the central and the south-western Alps, with annual totals between 500 and 950 mm/year.

In future, the yearly sum of precipitation is expected to slightly decrease up until the end of the century. Depending on the model and the region, the decrease ranges between – 1 % and – 11 %, with the strongest decrease in the south-western Alps. However, studies of seasonal variation indicate very different trends (Figures 2.6 and 2.7). The summers show the greatest change, with continuously declining precipitation in all scenarios and model runs. When considering, for example, the relative changes in the CLM A1B scenarios up to the end of the 21st century, the south-west will be most affected (– 41 %) and the north-east least affected (– 25 %). However, in spring most regions will receive more precipitation (NE + 24 %, NW + 16 %, SE + 8 %). It is only in the south-west that a slight decline (– 2 %) is projected.

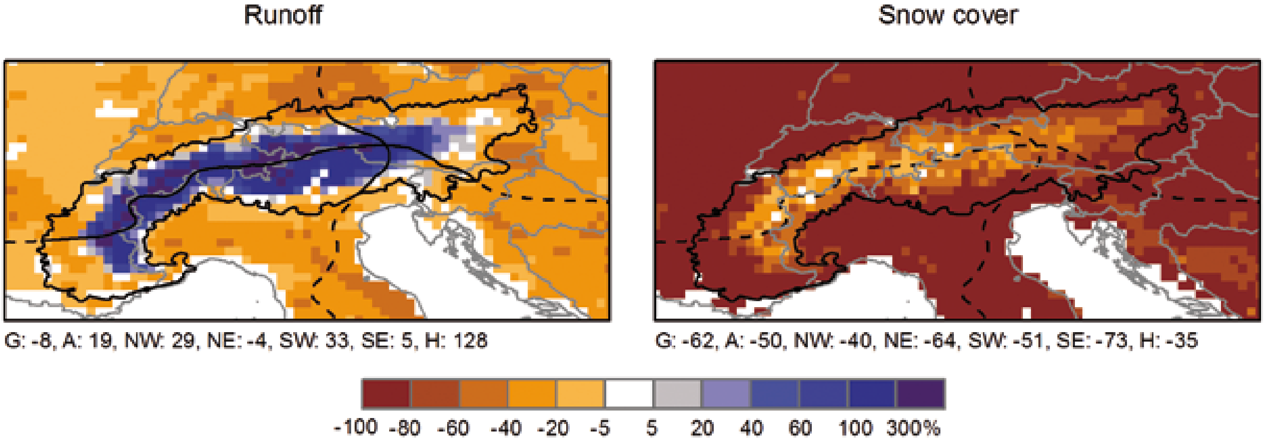
As a result of the changing precipitation patterns, there will also be a change in the incidence of dry periods (> 5 consecutive days without precipitation). Within the CLM A1B scenarios, the strongest change is projected for summer (+ 36 %), with the greatest relative increase in the northern Alps (NW + 73 %,

Figure 2.7 Changes in seasonal precipitation and run-off according to different emission scenarios in CLM



Source: EURAC, 2008, based on data from CLM climate scenarios (Lautenschalger *et al.*, 2008).

Figure 2.8 Run-off and snow cover change up until the end of the 21st century in the winter, according to the CLM A1B scenario



Note: Left: relative difference in water available for run-off. Right: relative difference in days with snow cover. Regional statistics: G = Greater Alpine Region, A = Alps, NW = north-western Alps, NE = north-eastern Alps, SW = south-western Alps, SE = south-eastern Alps, H = higher than 1 500 m.

Source: EURAC, 2008, based on data from CLM climate scenarios (Lautenschalger *et al.*, 2008).

NE + 52 %), where the number of dry periods is low under current conditions.

2.2.5 *Snow cover and snowfall*

Climate warming is projected to lead to an alpine-wide decline of days with snow cover. While the relative decline is similar in winter and spring, the rates differ significantly among the alpine regions. Most affected is the south-east, with more than 70 % decline in the CLM A1B scenario, whereas decline rates are about 40 % in the north-west (Figure 2.8). This picture becomes even more dramatic when the modelled absolute numbers are considered. An average winter at the end of the century would only have 11 days with snow cover in the south-east (spring: four days). In the north-west it would be 40 days in winter and 28 days in spring. However, with its 20 km resolution the CLM model cannot capture the very high topographic variability at a small scale. Hence local exceptions from these trends are likely in all regions.

Regarding snowfall, there could be a reduction of 36 % in the winter. Even at altitudes above 1 500 m the models calculate a reduction of about 20 % up to the late 21st century. The REMO results also suggest that below 500 m snow could nearly completely disappear (a reduction of more than 80 %; Jacob *et al.*, 2007).

2.2.6 *Run-off and the risk of droughts*

While changes in average yearly run-off totals are correlated with precipitation changes (a slight decline up until the end of the 21st century), they differ significantly from precipitation changes on a seasonal scale, particularly in winter and spring (Figure 2.7).

In these seasons, the amount of snow melt and changes in the proportion of precipitation falling as snow are stronger drivers for run-off change than precipitation alone. Higher temperatures will not only lead to increased rainfall and less snowfall but will also cause more snow to melt during the winter (rather than in the spring). This could lead on average to an increase in alpine winter run-off of up to 19 % (CLM A1B, Figures 2.7 and 2.8) as well as a decline in snow melt in spring of up to 40 % (REMO A1B) with a reduction in spring run-off of up to – 17 %. In particular, the strong decrease in summer run-off — which for some parts of the southern and central Alps is predicted as being up to – 55 % by the end of the 21st century — could cause problems with water availability within the Alps, and even more problems in the downstream regions.

As yet there is no clear evidence that droughts, defined as extended periods of water deficiency in a region, have become more frequent. Dry and hot years such as 2003 have shown that even within the Alps drought events can occur. The expected trends, a decrease in summer precipitation and an even more pronounced decrease in summer run-off, indicate that droughts are an extreme event for which even the Alps have to be prepared in future. First strategies have been discussed in Switzerland (see Schorer, 2000).

3 The Alps as water towers for Europe

Key messages

The Alps, characterised as 'water towers', play a fundamental role for water accumulation and freshwater supply for large parts of Europe. Water resources in the Alps are stored in glaciers, lakes, groundwater bodies and soil. Most of the major rivers, for example the rivers Rhine, Po and Rhone, have their headwaters in the mountains and their discharge is transported via river systems to lower-lying areas providing essential freshwater resource. Since the hydrological cycle of the Alps is influenced by meteorological and climatic processes, by topography and by the anthropogenic use of water, it is closely related to any changes in those parameters. Thus the Alps as 'water towers' are extremely sensitive and vulnerable to various impacts including climate change. Due to global warming, changes in precipitation regimes, snow cover patterns and glacier storage will alter the water availability. Most relevant conflicts in consequence of water-supply shortages can be expected at a local level in the south-eastern and south-western climatic sub-regions. In the future, lowlands dependent on water resources from the Alps may also face problems in both quantity and quality aspects. Potential conflicts have to be reviewed continuously and critically, and adapted to improved models of prognosis.

3.1 Contribution of alpine river catchments to water availability in Europe

Referred to as the water towers of Europe, the Alps represent an enormous natural water reservoir since precipitation in winter is retained as snow and ice. Considerable quantities of water can be accumulated and released through the summer melting of glaciers and snow fields, thus providing water during the season when precipitation and run-off are often least in the lowlands, and demands are highest. Particularly, this becomes effective in the dry, precipitation-poor months of late summer, when the Alps play a distinct supportive role with regard to overall discharge. This natural storage mechanism benefits many river systems throughout Europe, including the four major alpine river basins, the Rhine, Danube, Po and Rhône.

A comparison between the proportion of discharge that can be expected on the basis of catchment size and the actual discharge measured demonstrates the hydrological significance of the Alps (see Table 3.1). With a mean contribution ranging from 26 % (Danube) to 53 % (Po) of the total discharge, the Alps supply up to 2–6 times more water than might be expected on the basis of catchment size alone (disproportional influence, Weingartner *et al.*, 2007).

Since the hydrological cycle of the Alps is influenced by meteorological and climatic processes, by topography and by the anthropogenic use of water, it is closely related to any changes in those parameters. This chapter does not deal with climate change as such (see Chapter 2), but does give a first cross-boundary overview of the actual trends expected for alpine hydrology due to impacts of climate change and human activities, as well as the

Table 3.1 Contribution of the Alps to total discharge of the four major alpine streams

	Rhine	Rhône	Po	Danube
Mean contribution of the Alps to total discharge (%)	34	41	53	26
Areal proportion of total Alps (%)	15	23	35	10
Disproportional influence of the Alps	2–3	1–8	1–5	2–6

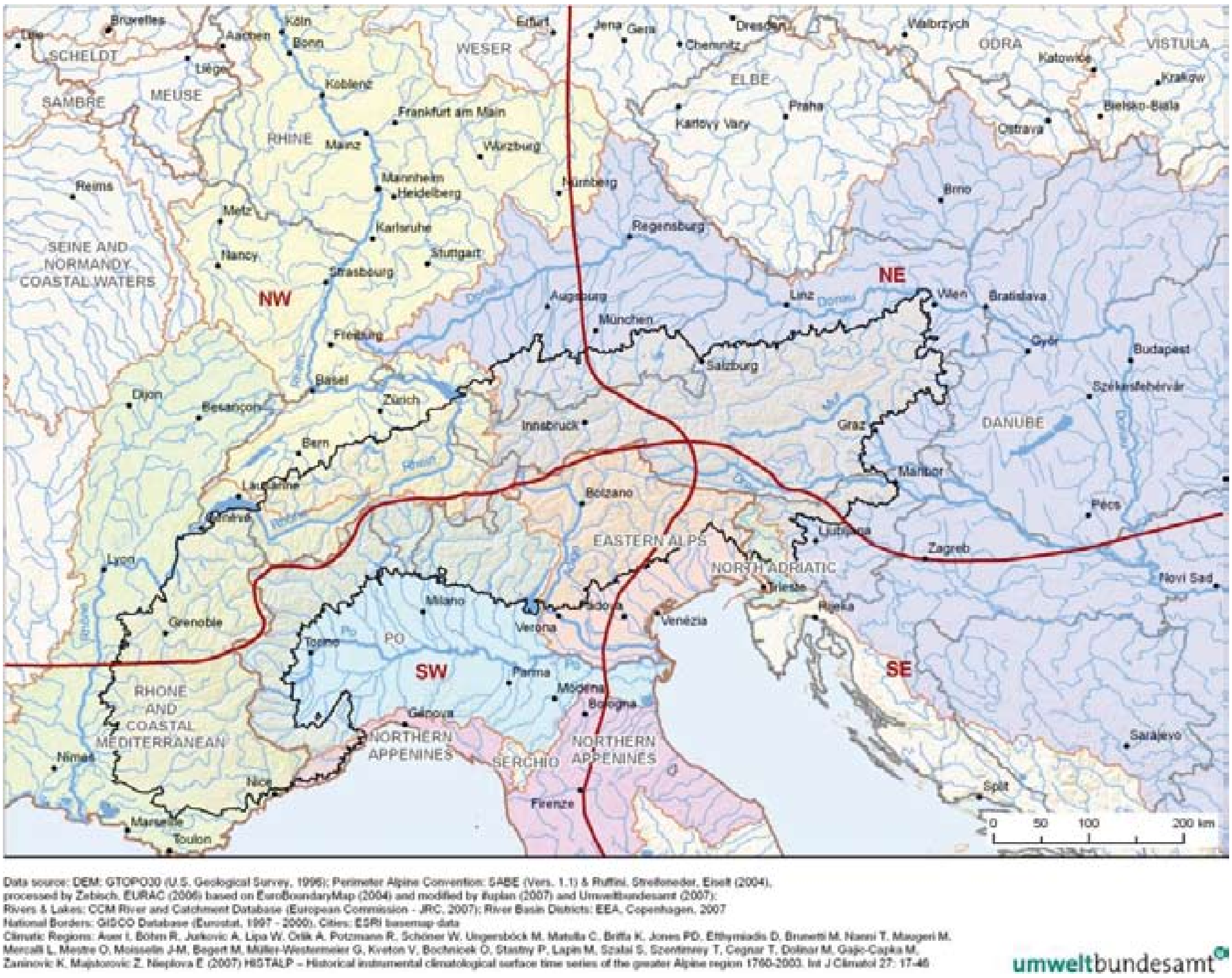
Source: Weingartner *et al.*, 2007.

characteristics of the main river basins in the Alps. The Alps referred to here is the region defined by the Alpine Convention (see Figure 3.1, indicated with black line).

With regard to water resources, the importance of the Alps is primarily based on enhanced precipitation due to the orographic effect; that is, rainfall generally increases with altitude. A large proportion of the precipitation falls as snow at higher altitudes, and may form glaciers, which are key features of mountain hydrology. Furthermore, lower temperatures at higher elevation result in lower evapotranspiration ([1]) rates, causing a positive water balance in the mountains.

In the Alps, around 5 150 glaciers presently cover about 2 909 km², approximately 1.5 % of the total area of the Alps. When temperatures rise during the summer, melt water is released into river systems and groundwater bodies precisely at the time when precipitation is at a minimum and water demand is at a maximum (Liniger *et al.*, 1998). Therefore, glaciers are important for water accumulation. However, due to higher temperatures and long dry periods it seems that they are becoming increasingly

Figure 3.1 The Alps, the main river basin districts and climatic sub-regions



Source: I. Roder, 2009.

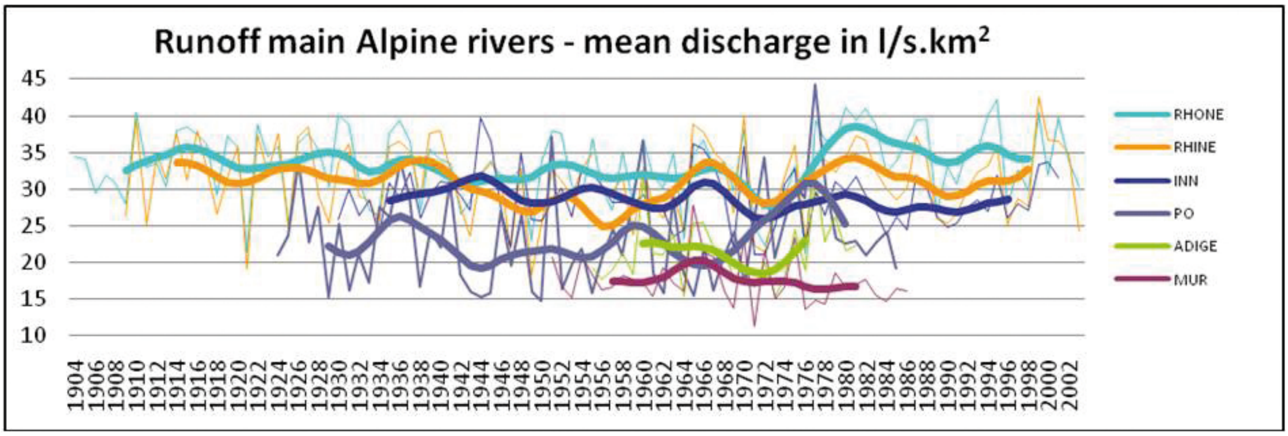
([1]) Evapotranspiration is a term used to describe the sum of evaporation (from sources such as soil, canopy interception and water bodies) and plant transpiration.

less able to fulfil this role in the Alps. Since 1980, alpine glaciers have lost about 20–30 % of their remaining ice. The hot summer of 2003 led to a loss of 10 % of the remaining glacier substance in the Alps (Haeberli, 2003).

Alpine catchments are characterised by much higher annual mean discharge per area (more than 30 l/s per km²) compared to catchments in the Central European lowlands (about 10 l/s per km²) (Liniger *et al.*, 1998). Between the alpine rivers, there are significant differences in annual mean discharge per area. Figures are partly influenced by the positions of the monitoring stations, but most of the differences are due to the climatic conditions and water usage. The rivers Rhone, Rhine and Inn (Danube catchment) show higher (28–33 l/s per km²) and more constant discharges per area, whereas the rivers Po, Adige and Mur show lower (17–24 l/s per km²) and more variable discharges (Figure 3.2, Table 3.2).

Within Europe, the Alps provide enormous quantities of water for multiple uses not only for the alpine region, but also for the surrounding areas and for large parts of Europe in general. Clean fresh water is essential for all aspects of our livelihood: from basic drinking water to food production and health, from energy production

Figure 3.2 Average yearly run-offs of the main alpine rivers — tendencies



Note: Bolt lines: 12-year moving average.

Source: Global Runoff Data Centre, 2008.

Table 3.2 Hydrological characteristics of Danube (Inn, Mur), Rhine, Adige, Po and Rhone at selected monitoring stations close to the Alpine Convention area

River basin district	River	Monitoring station	Catchment [km²]	Average 1960–1985 [m³/s]	Average 1960–1985 [l/s per km²]	LQ* 1960–1985 [m³/s] (year/month)	HQ** 1960–1985 [m³/s] (year/month)
Danube	Inn	Schärding	25 664	721 022	28.09	217 107 (1963/2)	2 372 433 (1965/6)
Danube	Mur	Frohnleiten	6 548	114 652	17.51	32 866 (1978/1)	462 333 (1965/6)
Rhine	Rhine	Neuhausen	11 887	372 078	31.30	128 032 (1972/3)	891 433 (1965/6)
Eastern Alps	Adige	Trento	9 763	214 255	21.95	75 803 (1972/1)	611 967 (1965/9)
Po	Po	Piacenza	42 030	1 019 184	24.25	220 000 (1965/5)	3 780 000 (1977/5)
Rhone and Costal Mediterranean	Rhone	Chancy	10 299	340 165	33.03	133 661 (1972/10)	740 452 (1980/7)

Note: * LQ stands for low discharge; ** HQ stands for high discharge.

Source: Global Runoff Data Centre, 2008.

to industrial development, from sustainable management of natural resources to conservation of the environment. Mountain freshwater also sustains many natural habitats, both in the Alps and in the lowlands. In turn, natural habitats are playing an important role for the preservation and maintenance of the water resources. Thus, careful management of the mountainous regions of watersheds must have the highest priority with regard to freshwater resources (Liniger *et al.*, 1998).

Due to climate change, higher temperatures will enhance the hydrological cycle in the Alps. This implies higher rates of evaporation and liquid precipitation, and a smaller rate of solid precipitation. These physical mechanisms, associated with potential changes in precipitation amount and seasonality, will affect soil moisture, groundwater reserves and the run-off regime. In addition, global warming will raise the snowline by 650 m by the end of this century (Jacob, 2001) and glaciers will continue to melt. It can be expected that small glaciers will disappear, while larger glaciers will suffer a volume reduction of between 30 % and 70 % by 2050 (Paul *et al.*, 2004; Bogataj, 2007).

Thus the Alps as 'water towers' are extremely sensitive and vulnerable to various impacts including climate change. Changes in local precipitation, snow cover patterns and glacier storage are likely to affect discharge from mountain-dominated territories in terms of timing, volume and variability and will influence run-off characteristics in the lowlands (IPCC, 2001). This in turn will influence human activities and interests that are highly dependent on water, such as hydroelectric power or agriculture (see Chapter 4).

3.2 The Danube (north-east)

The Danube comprises the second-largest river basin of Europe and the largest tributary to the Black Sea. Due to its large expanse from west to east, the Danube crosses three climatic zones: the Atlantic climate with high precipitation, the continental climate with lower precipitation and cold winters and the Mediterranean climate.

The Danube flows through, or borders on, territories of 10 countries (Germany, Austria, Slovak Republic, Hungary, Croatia, Serbia and Montenegro, Bulgaria, Romania, Moldova and Ukraine) and crosses four ecoregions (Central Highlands, Hungarian Lowlands, Carpathians and Pontic Province; European Parliament and Council (2000)).

The Danube begins in the Black Forest (Schwarzwald) in Germany at a height of about 1 000 m. Interestingly, the Danube loses about half its discharge to the Rhine basin through underground passages in its upper course near Immendingen (reduction from 12 to 6 m^3/s). The Danube flows predominantly to the south-east and reaches the Black Sea after 2 780 km. At its mouth,

Table 3.3 Characterisation of the Danube river basin

Length of river	2 780 km
Total catchment area	801 463 km^2
Inhabitants within catchment area	~ 81 million
Concerned states	Albania (126 km²), Austria (80 423 km²), Bosnia Herzegovina (36 636 km²), Bulgaria (47 413 km²), Croatia (3 4965 km²), Czech Republic (21 688 km²), Germany (56 184 km²), Hungary (93 030 km²), Italy (565 km²), the former Yugoslav Republic of Macedonia (109 km²), Moldova (12 834 km²), Poland (430 km²), Romania (232 193 km²), Serbia and Montenegro (88 635 km²), Slovak Republic (47 084 km²), Slovenia (16 422 km²), Switzerland (1 809 km²), Ukraine (30 520 km²)
Important tributaries	Lech*, Naab, Isar, Inn*, Traun*, Enns* Morava/March, Raab/Rába, Vah, Hron, Ipel/Ipoly, Sió, Drau/Drava*, Tysa/Tisza/Tisa, Sava, Tamis/Timis Morava, Timok, Jiu, Iskar, Olt, Yantra, Arges, Ialomita, Siret, Prut
Major uses	Navigation, hydropower, industry (chemical, food, textile, metal, paper, car, service etc.), agriculture, drinking water, local recreation

Note: * Alpine tributaries.

Source: ICPDR, 2005.

the Danube has an average discharge of about 6 500 m^3/s (ICPDR, 2005).

The Danube catchment of Austria lies mostly within the Alps and contributes to the run-off with 1 448 m^3/s, which is 22 % of the total run-off of the Danube river basin (ICPDR, 2005).

Four monitoring sites have been set up in the Danube recharge area in order to detect possible trends and relationships between run-off and levels of chemicals in alpine rivers caused by higher temperatures over the last 20 years. Data from these sites indicate that there has been a small increase in water temperature and that levels of nutrients as dissolved organic carbon (DOC), nitrate, ammonium and orthophosphate, have all decreased (GZÜV, 2008). However, this decrease in nutrients is mainly due to improved treatment of sewage water and declining use of fertilisers in agriculture. Although these trends are not yet significant, it is important that they continue to be monitored and analysed.

3.2.1 Climate change impacts

In the alpine recharge area of the Danube, the major alpine divide of the eastern Alps separates an area with general increasing trends in precipitation and discharge in the north and decreasing trends in the south (1951–2000). In addition, the seasonal trend shows a precipitation increase in autumn and an increase of discharge in winter (Fürst *et al.*, 2008). However, the summer precipitation and discharge is still the most important characteristic for the eastern Alps.

The drought in the summer of 2003 showed that the Alps can serve as an important water tower, since the overall water deficit in the upper Danube in 2003 was partly compensated for by increased glacial water due to excessive melting in the Alps. At the end of the summer, the water level fell to the lowest levels in over a century, stranding ships and barges from southern Germany to the Romanian lowlands. The hydro power plants along the Danube and its tributaries produced less electricity than normal. Romania's Cernavoda nuclear power plant, which draws coolant water from the Danube, was forced to shut down for almost a month (ICPDR, 2008).

3.3 The Rhine (north-west)

The Rhine is the only river connecting the Alps with the North Sea. It is the most important cultural and commercial axis of central Europe (Belz *et al.*, 2007; IKSR, 2005).

The two headstreams of the Rhine, the 'Vorderrhein' and the 'Hinterrhein' both originate in the canton of Grisons (Switzerland), in the transition zone of the Western Alps to the Eastern Alps. The source of the 'Vorderrhein' is close to the 'Oberalp Pass' at an altitude of 2 344 m and the 'Hinterrhein' rises at the 'Paradise Glacier' of the 'Rheinwaldhorn' peak. Geographically, the extensively populated area is characterised by valleys and mountain landscapes with peaks of up to more than 3 000 m. Due to high precipitation, several more springs originate in the headwater area. From the confluence onwards, the river is characterised by heavy regulation and major pressures from manifold uses, such as industry

Table 3.4 The Rhine — basic data

Length of river	1 320 km
Total catchment area	185 000 km^2
Inhabitants within catchment area	50–58 million
Nine riparian* states	Germany (approximately 100 000 km^2); Switzerland, France and the Netherlands (20 000–30 000 km^2); Austria and Luxemburg (approximately 2 500 km^2); Italy, Liechtenstein and Belgium (a small percentage)
Headstreams	'Vorderrhein' and 'Hinterrhein'
Important tributaries	Aare, Ill, Main, Nahe, Mosel, Ruhr, Lippe
Six major sections	Alpine Rhine (confluence — Lake Constance); High Rhine (Lake Constance–Basel); Upper Rhine (Basel–Bingen); Middle Rhine (Bingen–Cologne); Lower Rhine (Cologne–Dutch border); Rhine Delta
Major uses	Navigation (possible from Rotterdam to Basel; ships up to 3 000 t) hydropower, cooling water, industry (chemical, food, textile, metal, paper, car, service, etc.), agriculture, drinking water, local recreation

Note: * States located on the banks of the Rhine river.

Source: Belz *et al.*, 2007; IKSR, 2005.

and hydropower (IRKA and IRR, 2005, see also Table 3.4). In the section of the 'High Rhine', a major tributary, the Aare, enters the Rhine; the Aare rises at the Aare glacier and is intensively used for the generation of hydropower and cooling of nuclear power plants.

Due to the addition of tributaries (not originating in the Alps) along its course, the original nival-glacial discharge regime ([2]) is increasingly transformed into a pluvial regime ([3]) (Belz *et al.*, 2007). The alpine section, which constitutes only 15 % of the total catchment area, contributes, on average 34 % of the total discharge ([4]) at Lobith in the Netherlands, close to the German border (Viviroli and Weingartner, 2004a and 2004b). During the summer months, when the melting of snow (mainly May and June) and glacier ice (July and August) produces high and reliable discharge volumes, this discharge surpasses 50 %. With only approximately 1 % of normal monthly discharge in August at Basel (Belz *et al.*, 2007), the importance of glacial melt water is however rather low, depending on low glacier coverage (427 km^2) of the Alps where the Rhine and Aare rise (Belz, 2007). In addition to its considerable quantity, the alpine type discharge is also good quality, which makes it a valuable source for drinking water abstraction throughout its course (IKSR, 2005; IRKA and IRR, 2005; Viviroli and Weingartner, 2004a).

3.3.1 Climate change impacts

Changing climatic conditions in the latter part of the 20th century have already affected the discharge into, and hence the hydrology of, the Rhine. In the southern part of the catchment with a nival regime, changes in precipitation led to lower high-flow conditions in summer and higher low-flow conditions in winter. In contrast, in the northern part with pluvial regime, the already high-flow conditions in winter has been strengthened (Belz *et al.*, 2007). At the same time, the Middle Rhine has been experiencing low-flow conditions for slightly longer periods during the summer/autumn season (BMVBS, 2007). With further climate changes, these effects will increase in intensity. Furthermore, the increase in frequency and intensity of extreme events will lead to more extreme discharge regimes. Whereas in the past, adaptation focused only on flood protection (in particular in the Netherlands ([5]) but also in Germany ([6])), a response to low-flow conditions is now being formulated. The drought in 2003 played a major part in raising awareness: the prolonged hot and dry weather resulted in economic losses for shipping and the energy sector; and the higher than normal water temperatures and low oxygen content had a negative effect on riparian ecosystems (BfG, 2006).

However, in contrast to what might be expected, water quality was not affected by the decrease in discharge volume. This was primarily because the absence of precipitation meant that input of nutrients and other pollutants from agriculture and settlements was negligible. In 2005, due to an increase of melt water from the Alps, low-flow conditions were less accentuated in the nival-glacial influenced discharge regime of the Rhine. On the European level, the Water Framework Directive (WFD) requires the monitoring of the status of water bodies where climate change can have impacts, for example low flows, water scarcity and water excess (EEA, 2007).

3.4 The Po and the Adige (south-east)

3.4.1 The Po

From its source, Monviso Mountain in the Piedmont Region at 2 022 m, the River Po ([7]) flows 657 km to form a large delta outlet into the Mediterranean Sea. The Po basin covers about 4 000 km^2 in Switzerland and about 70 000 km^2 in Italy (Autorità di Bacino del fiume Po, 2006). This wide river basin, bordered to the north and west by the Alps and to the south by the Apennines, comprises approximately 2/3 mountainous environments and 1/3 plain, with

([2]) Discharge is affected by snow and snowmelt with maximum discharge in spring/summer and minimum in winter.
([3]) Discharge is fed by rain with maximum discharge in winter and minimum in summer due to evaporation.
([4]) Mean discharge (MQ, 1951–2000) Lobith: 2 220 m^3/s (Belz *et al.*, 2007).
([5]) For example, in the third national communication on climate change policies prepared for the Conference of the Parties under the Framework Convention on Climate Change (Ministry of Housing, Spatial Planning and the Environment Directorate Climate Change and Industry, 2001).
([6]) For example, elevation of flood risk assessment benchmarks following results of the 'KLIWA' Project (LUBW and LfU, 2006). Cooperation Partners are the German Meteorological Service (DWD), the Ministry of Environment Baden-Württemberg (UMBW), the Bavarian State Ministry of the Environment, Health and Consumer Protection of Bavaria (BayStMUGV) and the Ministry of the Environment, Forestry and Consumer Protection of Rhineland-Palatinate (MUFV RLP).
([7]) Data from the Po River Basin Authority.

Table 3.5 The Po — statistical data

Length of river	657 km
Total catchment area	74 000 km^2
Inhabitants within catchment area	~ 16 million (whole basin)
Concerned states	Italy (70 000 km^2) and Switzerland (4 000 km^2)
Important tributaries	Adda*, Agogna, Banna, Chisola, Dora Baltea*, Dora Riparia, Grana del Monferrato, Lambro, Maira, Malone, Meletta, Mincio*, Oglio*, Olona, Orco, Pellice, Rotaldo, Sangone, Sesia, Stura del Monferrato, Stura di Lanzo, Tanaro, Terdoppio, Ticino*, Varaita
Major uses	Hydropower, cooling plants, industry (chemical, food, textile, metal, car, service, etc.), irrigation for agriculture, drinking water, local recreation. Navigation limited due to the presence of reduced sections

Note: * Principal alpine tributaries.

Source: Po River Basin Authority, 2008.

a wide range of hydrological and geomorphological characteristics.

The discharge of the Po is a complex interaction of the influences of the Alps, the Apennines and the Mediterranean climate. Along its course, the river is fed by a reticulum of 25 alpine watercourses. On average the Alps contribute around 53 % of the total discharge of the Po (Viviroli and Weingartner, 2004b), this includes input from more than 600 km^2 of glacier areas.

The mean annual discharge at the closing section (Pontelagoscuro) is about 1 536 m^3/s (1972–2007), the maximum recorded discharge was 10 300 m^3/s (measured in the 1951 flood) and the minimum 168 m^3/s (July 2006).

Across the Alps there are numerous reservoirs that are used for hydro-electric energy production; in addition, large lakes work as natural reservoirs downstream. The 174 reservoirs situated within the Alps of the river basin manage 2 766 million m^3 of water per year. About 1 253 million m^3 is in natural lakes (the main natural lakes within the Po river basin are Maggiore, Como, Oglio and Garda) the rest (1 513 million m^3) is in artificial reservoirs, 143 reservoirs of which are used exclusively for electric power production (Autorità di Bacino del fiume Po, 2006). Other typical uses of water in the Alps are related to drinking water abstraction, irrigation, industry and snow production.

Climate change impacts

Since 1960 the annual mean water temperature in the Po river basin has risen by about 2 °C. If the current trend continues, forecasts indicate that the annual mean temperature will have risen additionally by 3–4 °C by the end of this century (Tibaldi *et al.*, 2007). During the period 1975–2006, precipitation in the Po river basin decreased by 20 % of the annual total and by 35 % for the months January to August. Analogous trends can be found in the Po river discharge data for the Pontelagoscuro section at the river delta, with a yearly 20 % decrease and further declining to a drop of 40 % for the summer season (Tibaldi *et al.*, 2007). A significant decrease in the amount of fresh snow and in the volume of the alpine glaciers has been observed. From 1860 to the present, a loss of the glacier surface of about 40 % has been registered.

The reduced water resource availability induced by climatic change is contributing to further deterioration of water status already affected by growing anthropogenic pressures (MATTM, 2006, 2007). The main effect of the lack of a minimum stream flow is the decrease of the water body self-cleaning capacity and the increase of salt wedge intrusion beyond the river delta. These problems are clearly evident in the plain of the Po river basin, where pressures are higher, both in terms of withdrawals and pollutants input, while in the mountain areas water quality is still at a good level. For the Italian classification method (D.Lgs 152/99), physicochemical indicators are summarised in the category 'level of macro-parameters pollution (LIM), where 'macro-parameters' are temperature, biological oxygen demand (BOD), dissolved organic carbon (COD), nutrients, dissolved oxygen and colibacteria. In mountain areas, these indicators are all under legal limits, therefore reaching a 'good status' classification (Autorità di Bacino del fiume Po, 2006, 2008). To mitigate the impact of the drought periods over the whole basin, a coordinated management protocol between all organisations involved in the Po river basin management has been established. The protocol deals mainly with the alpine region of the Po river basin, which contributes the largest amount of river discharge ([8]).

3.4.2 *The Adige*

The Adige ([9]) river basin covers an area of 12 160 km². The larger part of the basin is in Italian territory (Bolzano, Trento, Belluno, Verona, Vicenza, Padova, Rovigo and Venezia Provinces) while only a small part, 130 km², lies in Switzerland. The basin is essentially mountainous and an area of about 11 500 km² lies within the Alpine Convention area.

The Adige river rises at 1 586 m near Lake Resia and after a course of 409 km reaches the Adriatic Sea near the Albarella and Rosolina Municipalities. The basin is commonly subdivided into seven major sub-basins: Adige–Passirio, 3 173.7 km², Isarco–Talvera 2 058.9 km², Rienza 2 149.1 km², Noce 1 385.6 km², Avisio 939.5 km², Adige-Ferina-Leno 1 006.7 km² and Adige–Chiampo 1 463.7 km². The mean annual discharge at the Trento section (whose basin comprises roughly 80 % of the whole basin area) is about 185 m³/s (1926–2006), while at Boara Pisani section, just upstream from the delta, it is about 202 m³/s (1926–2006, data Adige River Basin Authority).

The average contribution of the Alps to the discharge of the Adige River basin has not yet been calculated; however it is reasonable to hypothesise that the contribution is significant since 94.6 % of the basin area is mountainous and the difference between the mean annual discharge measured at the Trento station and the closing of Boara Pisani is only about 17 m³/s (Adige River Basin Authority, Autorità di Bacino del fiume Adige, 2008).

In the alpine basin 185 glaciers and 31 reservoirs constitute the water resource of the basin. The glacial area covers about 212 km², while the management water capacity of the reservoirs is about 490 million m³. Typical uses of water at high altitudes in the Alps are related to hydropower production, while in the valleys the water is abstracted for drinking (about 2.5 m³/s) and irrigation (about 100 m³/s).

Climate change impacts
In the Adige river basin, the annual mean temperature has risen by between 1.3 °C and 1.5 °C, and mean annual precipitation has decreased by about 10 % (both evaluated over the years 1926–2006) (Autorità di Bacino del fiume Adige, 2008). Analogous trends can be found in the Adige river mean annual discharge. Furthermore, a significant decrease in the amount of fresh snow and in the volume of the alpine glaciers has been observed, while the estimation of the loss surface for the glaciers is still researched.

In the alpine basin of the river Adige, physico-chemical indicators that are found in the category 'level of macro-parameters pollution' (LIM), are largely under legal limits. Over the years 2000–2001 in the northern part of the basin, the 14 monitoring stations state that LIM reaches an 'optimum' status for three of these, a 'good' status for 10 and only one is in the 'sufficient' class. In the southern part, in 2004, all eight monitoring stations recorded a 'good' status for the LIM indicator (Provincia Autonoma di Trento, 2005 and 2006; Provincia Autonoma di Bolzano, 2007; Regione del

Table 3.6 The Adige — statistical data

Length of river	410 km
Total catchment area	12 160 km²
Inhabitants within catchment area	~ 1.3 million
Concerned States	Italy (12 030 km²) and Switzerland (130 km²)
Important tributaries	Rienza, Isarco, Passirio, Noce, Avisio, Fersina, Leno, Chiampo
Major uses	Irrigation for agriculture, hydropower, cooling plants, industry, drinking water, tourism

Source: Adige River Basin Authority, 2008.

([8]) More information about the river basin management is available on the Autorità di Bacino del Fiume Po website (www.adbpo.it). The protocol is not available on the Internet but can be obtained from the Autorità di Bacino del Fiume Po.
([9]) Data from Adige River Basin Authority.

Veneto, 2004). As is the case for the Po river basin, a coordinated management protocol has been activated, as the alpine water resource is the most important contribution to the discharge of the river and therefore the main contribution to mitigate drought effects in the lower part of the river.

3.5 The Rhone (south-west)

The Rhone is the largest river feeding freshwater into the Mediterranean after the Nile. The source of the river is the Rhone Glacier in a region of elevated peaks exceeding 4 000 m in the central part of the Alps in the Swiss canton of Valais.

The source region is under the influence of Atlantic, Mediterranean, Continental and Polar air masses that bring contrasting temperature and moisture regimes to the region, with annual precipitation totals of between 1 200 and 2 500 mm. Along its course through Switzerland, the Rhone receives water from a number of tributaries that are also essentially regulated by alpine cryospheric processes, i.e., where the winter snow-pack represents the major annual signal for discharge (Beniston, 2000). The major regulator of the river's discharge before entering into France is Lake Léman, western Europe's largest freshwater body that, among other things, helps buffer floods downstream. When the Rhone enters the lake near Montreux, it has an average annual discharge rate of about 1 100 m^3/s. As the river curves southward in France, it is joined by major tributaries in Lyon (Saone), Valence (Isère) and Avignon (Durance), that increase the average discharge close to the Rhone delta in Camargue to about 1 700 m^3/s. Throughout its course, the Rhone is characterised by a great diversity of climatic conditions, with alpine nival contributions between May and July and winter oceanic input (particularly for the Saone tributary). Close to the delta, south of Avignon, the Rhone enters into the Mediterranean regime, associated with generally hot and dry summers, mild and moist winters, and frequent extreme precipitation events in autumn. These sometimes result in flooding events in the tributaries flowing eastwards from the Cevennes Mountains.

The discharge of the river along its course can change according to seasonal and annual climate variability. In the past, large floods frequently occurred, with discharges up to 10 times the normal amount (Etchevers *et al.*, 2001). Civil engineering works constructed during the 20th century are capable of controlling minor flood events, but recent floods such as the record event of December 2003 (13 000 m^3/s), have shown that the river is far from flood-proof. Low waters occur in the Rhone's alpine region in winter and in the Mediterranean region in summer (Habets *et al.*, 1999). Severe drought conditions associated with major heat waves also, on occasion, contribute to critical conditions, particularly for riparian biological diversity and also for cooling of the many (nuclear) power stations between Lyon and Avignon.

During the 2003 heat wave, the electricity output from the power stations had to be curtailed because of insufficient and exceedingly warm water withdrawals. Long-term discharge averages have changed little over the past decades (no significant trend is seen close to the Mediterranean), although there is a substantial rise in very high discharge rates, with 10 of the highest discharges since 1850 occurring in the past 20 years. Surface water temperature has also risen along most of the river. In Lake Léman, seasonal stratification that marks the summer water regime now occurs a month earlier than in the 1980s. Measurements at the bottom of

Table 3.7 The Rhone — statistical data

Length	812 km (Swiss part: 261 km)
Total catchment area	95 500 km^2 (Swiss part: 10 100 km^2)
Inhabitants within catchment area	16 million (Swiss part: 1.2 million)
Riparian states	Switzerland, France
Important tributaries	Saone, Isère, Durance, Ain (in Switzerland: Vispa, Dranse, Arve)
Five major sections	Valais (Wallis) transect; Lake Léman; Jura transect; Provence transect; Rhone delta (Camargue)
Major uses	Hydropower, water for cooling power stations, irrigation for agriculture, industry, recreation, navigation (up to Lyon; beyond Lyon on the Saone and on the Rhone-to-Rhine canal system)

Source: Adapted from Encyclopaedia Britannica.

the lake also confirm the long-term warming trends, showing an increase of almost 1.5 °C since the late 1950s (Fruget *et al.*, 2001).

Pollution levels along the Rhone have also shifted with time. High phosphate levels associated with run-off from agriculture and untreated waste waters prior to the 1990s have substantially improved. Lake Léman, which is a good indicator of slow-moving waters and therefore a body of water that has the ability to accumulate pollutants, shows dissolved phosphorus has reduced from peak annual levels in the mid-1980s of about 60 µg/L to less than 20 µg/L 20 years later. This is a result of policies aimed at prohibiting phosphates in detergents that were implemented first in Switzerland and then in neighbouring France. Dissolved oxygen was low in the 1980s and 1990s because of eutrophication and insufficient overturning of deep water, but the situation has improved in the early part of the new millennium. On the other hand, pollution probably of industrial origin, particularly downstream of Lyon, has exceeded tolerance levels beyond their legal limits. Since 2003, consumption of fish in several parts of the Rhone is prohibited because of the problems that could arise as a result of excessive pollution by substances such as PCBs. Ecological organisations also frequently raise questions as to the possibility of radioactive spills from the many French nuclear power stations along the Rhone and the long-term contamination that would result.

3.5.1 Climate change impacts

Because of the high dependence of the Rhone on nivo-glacial elements in the Alps, there is today sufficient evidence of glacier retreat, permafrost reduction and snowfall decrease over the past decades to suggest that climatic change may seriously affect stream-flow regimes, in turn threatening the availability of water resources, impacting hydropower generation, agriculture, forestry, tourism and riparian ecosystems. Based on recent research, warmer winter temperatures and hot summers, associated with seasonal precipitation shifts (more rainfall in winter but much lower rainfall in summer) will result in very different flow regimes in coming decades. It is expected that snow will melt earlier in the season (by up to 2 months) and on average snow amount will be reduced, so that peak flows will be lower than at present (Noilhan *et al.*, 2001). During long, dry summers, with little input from precipitation, no significant late spring/early summer snow and sharply reduced glacier melt-water contributions, discharge will be very low in the alpine domain. These low flows will be compounded in France along the course of the river to the Mediterranean because of stronger summertime evaporation and water uptake for agriculture, industry and energy.

Photo: © Torsten Grothmann

3.6 River basin management challenges

The Alps, characterised as 'water towers of Europe', are of central importance not only for the Alps themselves, but also for surrounding areas and for large parts of Europe in general. Climate change effects are already evident in the alpine river basins. During the 2003 heat wave, the importance of the Alps as water towers became even more obvious, although problems between different water users at a local level could not be avoided. However, based on the fact that climate projections are fairly approximate, potential conflicts at local and regional levels amongst water users are likely to increase in the future. Such conflicts must be handled with care. Potential cause of conflict should be reviewed and measures put in place to mitigate them.

Conflicts occur most often because of water scarcity and will be more likely in the south-eastern and south-western climatic sub-regions. Causes will include:

- decreased precipitation and increased evapotranspiration and in consequence lower outflow during long dry periods particularly in the summer period;
- reduced groundwater recharge and increased concentrations of natural mineralisation and anthropogenic pollution due to longer transfer time to springs and wells and increased water temperatures; changes in groundwater-dependent ecosystems;
- seasonal changes of precipitation and discharge with longer periods of dryness;
- changes in biocoenosis ([10]).

Shortage in water supply will result in conflict outside the Alps and will affect:

- drinking water supply;
- irrigation of agricultural areas;
- industrial water use;
- hydroelectric power production;
- cooling water supply;
- navigation opportunities along major rivers.

The proposed and (in some areas) already observed decreased amount of precipitation in combination with increasing temperatures will cause a shortage in discharge in springs and rivers. Similar to these effects, groundwater recharge will decrease regionally with some delay. This will contribute to the above-listed water conflicts mainly in the lower parts of the river basins. These conflicts can be partly compensated by the orographic effect ([11]) of the Alps but will strongly increase in long dry periods, especially in the south-eastern and south-western climatic sub-regions of the Alps, as the different water uses interact and aggravate the problems.

([10]) Biocoenosis: an ecological community, all the interacting organisms living together in a specific habitat.
([11]) The impact of varying topography on atmospheric circulations, including precipitation and temperature.

4 Water resources, climate change and adaptation options in sectors

Key messages

This chapter gives an overview of the most important climate change impacts upon water resources and adaptation options for the following water-sensitive sectors: biodiversity conservation, households, forestry, agriculture, tourism, energy, industry and river navigation. These systems and sectors were identified for this report as the most relevant sectors for the Alps. Taking an integrative perspective on these different water uses is important and explicitly addressed by an ecosystem services approach that includes measures for cross-sectoral adaptation.

Generally, in the short term the effects of climate change may result in new opportunities for some sectors, for example energy. In the longer run, however, climate change is likely to have negative effects on all sectors, especially if no adaptation measures are taken. In biodiversity conservation, autonomous adaptation of the organisms and ecosystems has to be supported and the original habitats have to be maintained. In the future, agricultural and forestal production will have to adapt to increasing water stress through the selection of suitable plant species. To some extent, improved water management will be needed, including water-efficient irrigation systems. Water-saving measures will also have to be enforced in the tourism sector, and tourism will have to be diversified towards sustainable options. Although drinking water resources seem to be abundant, in remote areas without a major water supply network, water for household consumption might become scarce due to increasing demand, especially during dry spells. Energy, industry and river navigation will be affected by larger seasonal variations in water availability. In particular, warm water temperatures and low-flow conditions may result in decreased productivity within these sectors.

4.1 Ecosystem services and cross-sectoral adaptation

Increasing temperatures and a changing precipitation regime (i.e. in general less precipitation in summer and more in winter) as well as an increase in climate variability and extreme events (see also Chapter 2) will affect natural and socio-economic systems and sectors in the Alps. This report focuses on the following systems and sectors: biodiversity conservation ([12]), households, forestry, agriculture, tourism, energy, industry, and river navigation. These sectors seem to be the most sensitive to the impacts of climate change upon water resources. Each of them relies to some extent on the provision of ecosystem services, and hence on the environmental management of the Alps.

4.1.1 Relevance

The ecosystem service approach provides a framework to understand the interlinkages between sectors with regard to direct (for example, forestry) or mostly indirect (for example, industry) dependency on the environment. 'In the recent decades we have moved from understanding humans as being reactive to their environment (pre-1980s), to thinking of environmental crises as being caused by humans (1980s), to thinking of environmental crises as being caused by socio-natural interaction (1990s) (van der Leeuw, 2001). In the present decade, we have also begun to understand human crises as caused by socio-natural interaction. A change in our environment can be considered a crisis when it threatens our livelihood or well-being. An environmental crisis will often

([12]) Biodiversity can be measured on many biological levels, ranging from genetic diversity within a species to the variety of ecosystems on Earth, but the term most commonly refers to the number of different species in a defined area.

leads to a human crisis (Schröter, 2009). Humans rely on ecosystems, because they depend on ecosystem services (Daily, 1997; de Groot, 1992).

Ecosystem services means the benefits humans obtain from ecosystems. Based on the 'Millennium Ecosystem Assessment' four types of ecosystem services can be differentiated (see Figure 4.1; Millennium Ecosystem Assessment, 2005; Körner *et al.*, 2005):

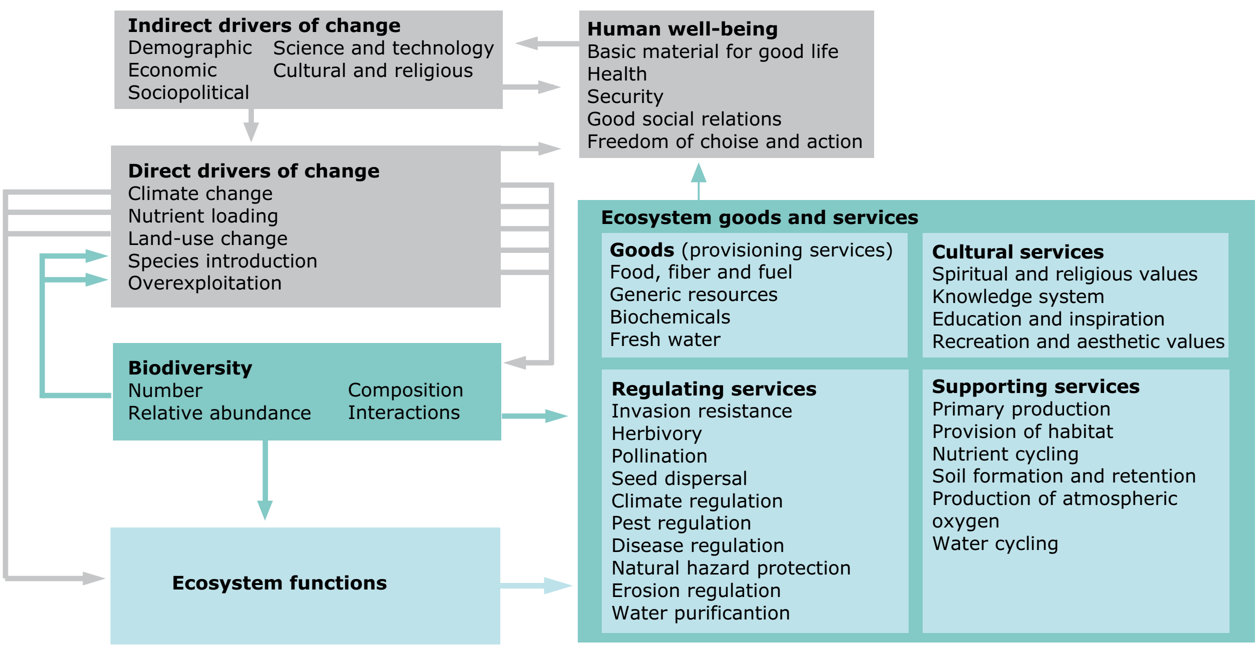
- provisioning services (goods): extractive resources that primarily benefit lowland populations (water for drinking and irrigation, timber, and so on) and ecosystem production (agricultural production for local subsistence and for export; pharmaceuticals and medicinal plants; and non-timber forest products);
- cultural services: spiritual role of mountains, biodiversity, recreation, and cultural and ethnic diversity;
- regulating services, such as hazard prevention, climate modulation, migration (transport barriers/routes), water purification;
- supporting services, such as soil formation, photosynthesis, water and nutrient cycling.

Each of these mountain ecosystem services makes specific contributions to lowland and highland economies.

Traditionally, effects of global change (including climate change) on ecosystems have been analysed separately from effects on food and fibre production, health, recreation, settlements etc. In contrast to this view, the ecosystem service concept leads to the recognition that ecosystems mediate global change (Schröter, 2009). Therefore, environmental impacts of global change can add to human vulnerability by altering the supply of ecosystem services, which are fundamental to human well-being (Metzger and Schröter, 2006; Schröter *et al.*, 2004; Schröter *et al.*, 2005).

Water is an essential resource for all human sectors. Water-related ecosystem services such as water purification, retention and storage vitally connect human sectors that may, at first sight, seem independent of each other; for example, forestry and industry. Ecosystems have a significant role in determining quantity and quality of water resources. With regard to groundwater recharge, mountain vegetation may change run-off patterns as well as soil–water movement, thus influencing the way groundwater is formed from precipitation. The excess water that is not used by the vegetation or

Figure 4.1 Ecosystem services and drivers of change



Source: CBD, 2008a.

held in the topsoil is slowly transferred to shallow groundwater aquifers, which in turn steadily release water even after periods of drought and thus provide a reliable source of water. In terms of water quality, vegetated soils can purify rainwater by adsorbing contaminants during its passage through the different soil layers. The quality of the filtered water strongly depends on the composition, constitution and depth of the soil as well as the top vegetation layers. Thus the presence of developed soil plays an essential role in maintaining the filter function and producing groundwater of high quality. The maintenance of mountain vegetation and soils (especially permafrost) is also important for climate regulation via evapotranspiration and shading; and in the long term, via biospheric carbon storage. However, it is important to realise that the potential of biospheric carbon storage is limited relative to current emissions. Terrestrial ecosystems are a source of carbon dioxide (CO_2) and other greenhouse gases when cut down, but they become a net sink during regrowth (for example, afforestation and reforestation ([13]).

This report focuses on water resources excluding floods and other natural hazards, since they have been addressed sufficiently in other reports (see Chapter 1). Nevertheless, the importance of mountain ecosystems in reducing risks from natural hazards will be described briefly in this context. One fifth of the forests in the Alps play an important role in protecting settlements and infrastructure from natural hazards such as avalanches and rock falls (CIPRA, 2001) as well as in flood prevention (Anderson *et al.*, 2008). Forest soils, which have a higher water storage capacity than non-forest soils, reduce run-off peaks and local flooding. Moreover, forest vegetation stores water and delays soil saturation. Evapotranspiration from mature forests can remove a considerable proportion of storm rainfall. In addition low-stature vegetation (for example lightly grazed grassland) is equally effective in maintaining a balanced run-off regime (Körner *et al.*, 2005). Surface run-off can therefore be prevented or slowed to some extent, even in high precipitation events. At the local level the effect of flood reduction is particularly relevant for small watersheds and minor meteorological events.

Cultural ecosystem services are of particular importance to the alpine population. The Alps, though geologically a young mountain range, are culturally among the oldest mountains in the world. People and nature have evolved over centuries to form a diverse entity that is world-famous for its cultural and natural richness. This fame attracts tourists from the European lowlands and far beyond, building a large tourism industry in summer and winter, and re-shaping the alpine landscape. To guide this relationship back onto a sustainable track, climate change impacts on cultural ecosystem services with particular regard to the dependency on alpine water resources have to be considered, in addition to direct human impacts. The alpine landscape is changing, and with it the cultural services it provides.

4.1.2 Water-related effects of climate change

Mountain ecosystems are strongly interlinked with the hydrological cycle, which was fundamentally altered through global warming over the past several decades. In the southern Alps, groundwater levels in some regions dropped by 25 % over the past 100 years (Harum *et al.*, 2007). This, together with the shrinking of glaciers, permafrost and snow cover, changes in precipitation patterns and increasing temperatures, will severely change alpine habitats and thus influence the ecosystem services they provide. The frequency of catastrophic hydrological extremes could increase, alternating between drought and rapid run-off with downstream flooding. The extremity of water flows could further lead to soil erosion, landslips, and sedimentation. Changes in soil quality could in turn reduce water quality and lead to the gradual and pervasive degradation of rivers. Given the strong interdependency of factors that lead to ecosystem changes, it has to be taken into account that impacts on one ecosystem process may — as a consequence — alter other processes in the ecosystem. When ecosystems and their processes change, multiple ecosystem services are likely to be affected.

Due to climate change impacts, existing competition for water resources between different systems and sectors could intensify in the future (OcCC/ProClim, 2007; de Jong, 2008) or new competition could emerge in regions without any experience in managing water use between sectors. Especially during the summer months, for which climate change scenarios project much drier and warmer conditions, competition for water will probably increase. More pronounced climatic changes are expected in the southern Alps,

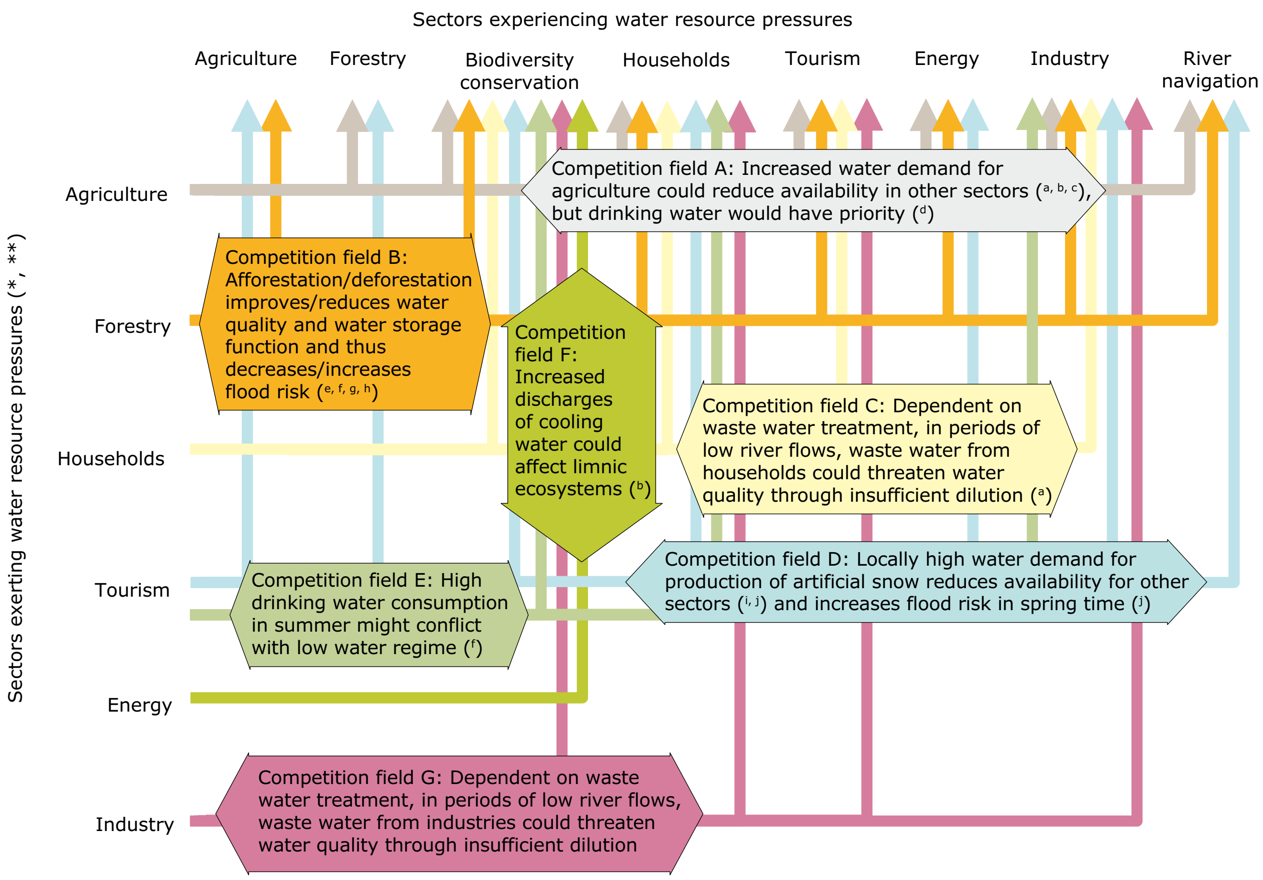
([13]) Afforestation is the process of establishing a forest on land that is not a forest, or has not been a forest for a long time, by planting trees or their seeds. The term reforestation generally refers to the reestablishment of the forest after its removal, or planting more trees, for example from a timber harvest.

thus water conflicts could become more severe in this region.

In this section of the report — building upon the ecosystem services framework — a cross-sectoral perspective is taken. Biodiversity conservation and households are also referred to as sectors. So called 'competition fields' are named, which summarise major potential impacts of water use in one sector on other sectors. Figure 4.2 illustrates the most important areas of cross-sectoral water competition currently experienced and anticipated in the European Alps. It roughly differentiates between sectors exerting water resource pressures (primarily agriculture, households, tourism and energy production) and sectors experiencing water resource pressures with regard to quantity and quality aspects (primarily agriculture, biodiversity conservation, households and energy production). This report discusses the specific 'competition fields' in detail — based on available literature. However, it cannot cover all potential interactions.

Locally, limitations in water resources seem to be induced in particular by the tourism sector (see competition field D in Figure 4.2). In some winter tourism regions, water consumption for snow production has already caused local conflicts with drinking water supplies (Thiebault, 2008). However, snow production takes place in early months of the year, when precipitation and run-off may actually increase due to climate change. The precipitation scenarios presented in Chapter 2 project that in spring most regions of the Alps will receive more precipitation. Only in the south-west a slight decline is projected. On the other hand, the projections

Figure 4.2 Fields of potential cross-sectoral water competition relevant for adaptation



* River navigation is not considered as a sector exerting water resource pressures as it uses but does not consume water.

** Biodiversity conservation is not considered as a sector imposing water resource pressures as it does not actively change water use pattern but rather can be considered as a sector exposed to water competition.

Sources: (a) OcCC/ProClim, 2007; (b) BUWAL and BWG, 2004; (c) Oleson *et al.*, 2005; (d) Wilibanks *et al.*, 2007; (e) IPCC, 2008; (f) Leipprand *et al.*, 2007; (g) Anderson *et al.*, 2008; (h) Giller and O'Holloran, 2004; (i) OECD, 2007; (j) Teich *et al.*, 2007; (k) de Jong, 2008.

for winter range from increases to decreases in precipitation. Several impacts of artificial snow production on ecosystems have to be expected (SLF, 2002; Teich *et al.*, 2007). For example, artificial snow, which is generally denser and therefore melts more slowly than natural snow, leads to changes in soil physics, hydrology and vegetation. The future development of the tourism sector remains unclear to a certain extent; a shift from skiing tourism in winter to summer tourism is expected as the Alps could benefit from exceedingly hot temperatures in the Mediterranean region (Müller and Weber, 2008). This would lead to even greater use of drinking water by tourists in summer, when precipitation and run-off is expected to be decreased by climate change — potentially resulting in conflicts with the needs of households and other sectors (Leipprand *et al.*, 2007, see competition field E in Figure 4.2).

The water demand of the energy sector is high, with hydropower and thermal power the most water-intensive energy sources. The influence of hydropower on the temporal variability of the hydrological regime and the influence of thermal power stations on river temperature can be considered as especially relevant. Increasing water temperatures could have adverse effects on limnic ecosystems, not only through higher temperatures but also by decreasing oxygen concentrations (OcCC/ProClim, 2007, see competition field F in Figure 4.2). Water consumption for irrigation in agriculture in the European Alps is not yet quantifiable, but an increase is expected for some regions in the future, which could lead to competition with other sectors (OcCC/ProClim, 2007; BUWAL *et al.*, 2004; ProClim, 2005; Oleson *et al.*, 2005; see competition field A in Figure 4.2). Yet, in the case of severe regional water shortages, drinking water would have priority over other uses (Wilbanks *et al.*, 2007). The forest sector influences hydrology through its water retention capacity. Afforestation could reduce siltation and floods in rivers and thus buffer the hydrological regime and improve water quality, whereas deforestation invokes the opposite (Anderson *et al.*, 2008; Leipprand *et al.*, 2007; Giller and O'Halloran, 2004; IPCC, 2008; see competition field B in Figure 4.2). On the other hand, the forest sector also qualifies as a water consumer (for example, Wattenbach *et al.*, 2007), and water loss through evapotranspiration is likely to increase at higher temperatures.

Depending on waste water treatment, households could negatively affect other sectors during periods of low river flows, when waste water discharges could pollute streams or rivers due to insufficient dilution (OcCC/ProClim, 2007; see competition

Photo: © European Environment Agency

field C in Figure 4.2). There is a lack of data on water consumption by the industrial sector in the Alps. Cross-sectoral competition could arise due to waste water generated in industries, which could threaten water quality of streams in periods of drought, and the sector's general need for good water quality (competition field C in Figure 4.2). On the other hand, waste water treatment has been greatly improved over the last decades in Europe. In addition, it is important to stress the link between water provision and energy demand in this context (not included in Figure 4.2). Higher water use also results in higher energy use (energy for pumping, water treatment). Therefore, higher water use efficiency represents a climate protection option.

In many sectors water use is not evenly distributed over the year. Therefore, in some cases water competition arises in specific periods of the year. For example, water for the energy sector is needed throughout the year with a peak in the winter season due to the heating demand. A rising demand for electricity and water for snow production in the tourism sector thus falls within a period in which energy production is already high and river flows are low (CIPRA, 2004; de Jong, 2008). In the long run a shift in energy production from winter to summer is expected in the future due to decreased heating in winter and an increased demand for indoor cooling in summer (BFE, 2007a; Prettenthaler *et al.*, 2007), which would then coincide with the period of a probably increasing water demand for summer tourists, filling water reservoirs and agricultural water abstraction.

4.1.3 Adaptation options

Various policy and management approaches can be applied to adapt to climate change impacts upon water resources and ecosystem services. Chapters 6 and 7 of this report will present these approaches in more detail. In this section of the report two approaches are discussed: the ecosystem approach of the Convention on Biological Diversity (CBD) and Integrated Water Resource Management (IWRM). Both seem especially suited to manage climate change impacts in an integrative and sustainable manner — including adaptation options to avoid and minimise cross-sectoral competition. In both approaches the concept of ecosystem services provides a clear language for discussing the diversity of user needs as well as the impacts of management and global change factors on the supply for these needs (Schröter, 2009).

The CBD defines its ecosystem approach to management as a 'strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way', which can be used for aligning adaptation activities. One point proposed as operational guidance to implement the CBD's ecosystem approach (CBD, 2008b) is that ecosystem management should involve a learning process, which helps to continuously adapt methodologies and practices to approaches that prove to be effective in practice. Ecosystem management needs to recognise the diversity of factors affecting the use of natural resources, including climate change. Similarly, there is a need for flexibility in terms of an adaptive management approach that builds on its results as it progresses. This 'learning by doing' will also serve as an important source of information on how best to monitor the results of management and evaluate whether established goals are being attained.

The integrative and long-term IWRM framework promotes coordinated development and management of water, land and related resources to maximise economic and social welfare in an equitable manner without compromising the sustainability of ecosystems (GWP, 2000). Through an integral perspective on cross-sectoral water resource uses, the IWRM provides a framework to improve and enhance existing management structures and increase efficient water uses — it also works by shifting foci from supply side management to demand management. IWRM is one of the guiding principles for the EU Water Framework Directive.

Both approaches need to incorporate adaptation to climate change more explicitly. To deal with the uncertainties of climate change impacts, low-regret and win-win measures, which deliver benefits under any foreseeable climate scenario, including present day climate, should be identified (Anderson *et al.*, 2008; Kurukulasuriya and Rosenthal, 2003; Lemmen and Warren, 2004; Willows and Connell, 2003). For example, increased storage capacities of water reservoirs are advantageous during droughts and flooding. However, this strategy might contradict the strict goals of the EU Water Framework Directive, which prohibits any aggravation of the ecological status of a river. Adaptation, particularly individual adaptation measures, in general depend very much on local conditions and will to a large extent occur at a decentralised level (Anderson *et al.*, 2008). Therefore, local and regional efforts maintaining or enhancing resilience against potential damage seem of particular importance (Opdam and Wascher, 2004). For long-term adaptation, a trend-setting political and socio-economic framework is necessary ([14]) embedding adaptation to climate change into sectoral policies (Anderson *et al.*, 2008), especially since climate change is usually only one driving force among others (Lemmen and Warren, 2004). In addition to long-term adaptation measures, response to drought situations should be prepared by developing short-term response plans (EC, 2008). Based on a monitoring and warning system, necessary counteractive measures can be taken in a timely manner to avoid situations of severe water scarcity (LAWA, 2007). Generally, activities to monitor and collect data on water uses and requirements form the basis for long- and short-term adaptation strategies and for the implementation of policies (GWP, 2000).

The rest of this chapter describes in detail the impacts of climate change upon water resources. It also considers adaptation options for the most water-sensitive sectors in the Alps: biodiversity conservation, households, forestry, agriculture, tourism, energy, industry and river navigation.

4.2 Biodiversity conservation

4.2.1 Relevance

The intrinsic value of biodiversity, apart from any direct human interest, is widely recognised. Respecting biodiversity is a main imperative of the precautionary principle ([15]). Furthermore,

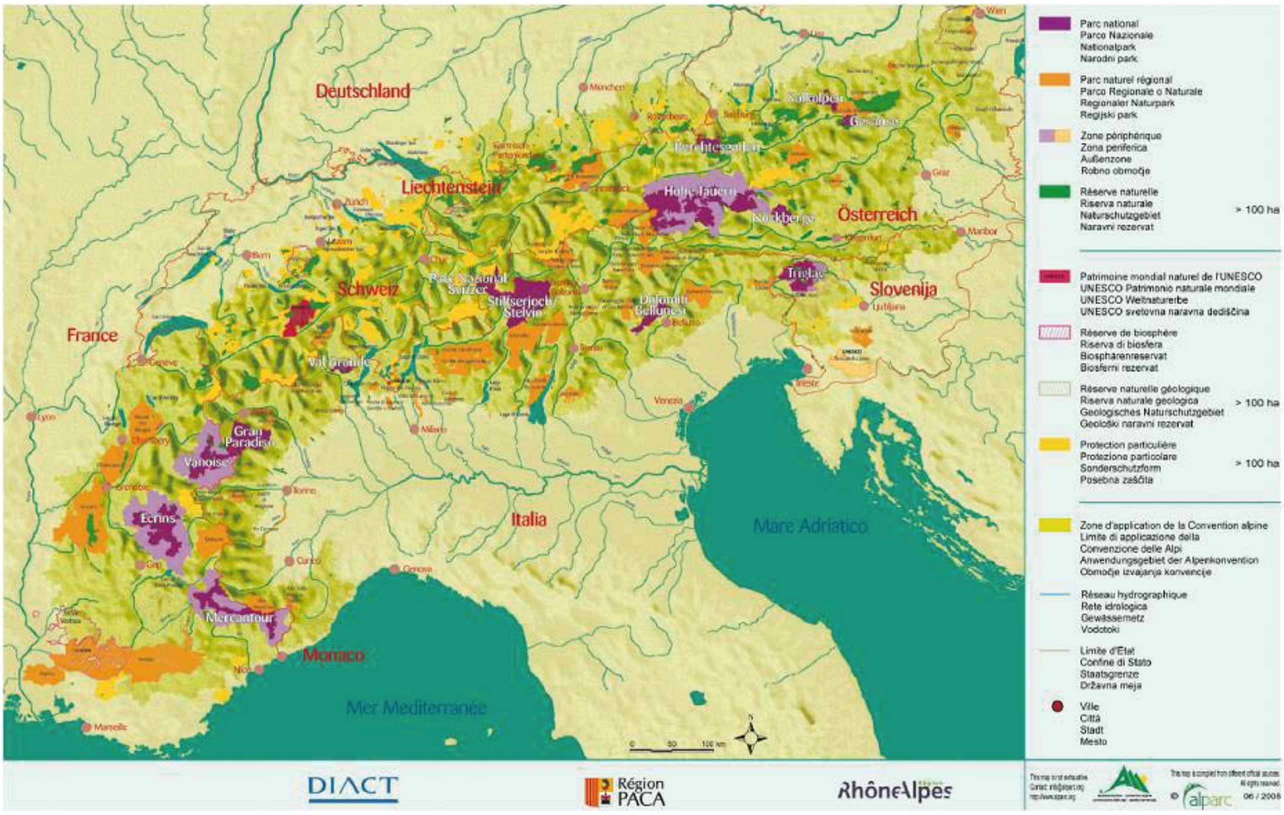
([14]) As envisaged for example by the EU Green Paper *Adapting to climate change in Europe — Options for EU action*

([15]) The precautionary principle is a moral and political principle which states that if an action or policy might cause severe or irreversible harm to the public or to the environment, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action.

biodiversity influences the provision of ecosystem services vital to humanity. Generally it is assumed that maintaining ecosystem integrity and health will sustain ecosystem service supply. Loss of biodiversity implies loss of services and therefore reduced human welfare. Past ecosystem degradation has been shown to have negative effects on human well-being (Millennium Ecosystem Assessment, 2005).

The Alps form an old cultural landscape, with socio-ecological properties that cannot be found elsewhere on the planet. Society and nature in these mountains have co-evolved to form a tightly knit and unique web of interaction, attracting people temporarily as tourists, or permanently as migrants from near and far. Among the European mountains the Alps, together with the Pyrenees, are richest in vascular ([16]) plant species (Väre *et al.*, 2003). They host about 4 500 plant species, which represents more than a third of the flora recorded in Europe, with almost 400 plants being endemic (prevalent in a particular area or region) (Theurillat, 1995). Plant biodiversity is particularly concentrated in high alpine regions. The area above the tree line is only 3 % of Europe's total area, but hosts 20 % of its plant species richness (Thuiller *et al.*, 2005). The fauna of the Alps may comprise up to 30 000 species (Chemini and Rizzoli, 2003). Climate change and intense agricultural practices are already threatening a number of species and unique habitats: for example, greyling (*Thymallus thymallus*), brown trout (*Salmo trutta fario*), black grouse (*Lyrurus tetrix*) and mountain hare (*Lepus timidus*), as well as riparian forests and many alpine plant species (Niedermair *et al.*, 2007). Habitat loss, fragmentation, changes in agricultural practice and pollution act in concert with climate change, and are among the most significant reasons for biodiversity loss in the Alps. Alpine protected areas play an important part in preserving natural and cultural heritage. The first national park in the Alps was established in 1914.

Figure 4.3 Protected areas in the Alps



Source: Alparc, 2009.

([16]) Plants with a dedicated transport system for water and nutrients are called vascular plants. Vascular plants include ferns, conifers and flowering plants.

Today, protected areas, over 100 ha, extend over approximately 23 % of the Alps (Alparc, 2009) (see Figure 4.3).

4.2.2 Water-related effects of climate change

The sensitivity of alpine biodiversity to climate change has been underlined by models (Schröter *et al.*, 2005; Thuiller *et al.*, 2005) and validated by *in situ* observations: upward shift of vascular plants, changes in species composition and the threat of extinction of endemic plant species (Grabherr *et al.*, 1994; Walther *et al.*, 2005; Pauli *et al.*, 2003; Pauli *et al.*, 2007). Changes in mountain flora will be driven particularly by reduction in snow cover duration and increased length of growing season, while direct temperature effects on metabolism are secondary (IPCC, 2007, Bavay *et al.*, 2009, Stewart, 2009, Vanham *et al.*, 2009). The tree line is projected to shift upward by several hundred meters (Badeck *et al.*, 2001). Quite clearly, climatic changes, in concert with ongoing abandonment of traditional alpine pastures, will restrict the alpine zone to higher elevations, severely threatening the alpine flora (IPCC, 2007). Projected local species losses are exceptionally high in mountain systems (up to 62 % of local plant species by the 2080s under the A1 scenario (Thuiller *et al.*, 2005). Migration of flora and fauna further up to stay within their bioclimatic envelope is limited in mountainous systems, quite abruptly, by the maximum altitude of the mountains. Moreover, the dispersal capabilities of many alpine species are limited (Grabherr *et al.*, 1994), and may be further restricted by habitat fragmentation (Higgins *et al.*, 2003).

The effect of climate change on alpine aquatic systems is as yet less-well studied. However, a number of cold-water fish species are reported to be stressed already by warmer water temperatures, in addition to other anthropogenic pressures (namely greyling (*Thymallus thymallus*), brown trout (*Salmo trutta fario*), perch (*Perca fluviatilis*), cisco (*Coregonus* spec.) and Danube salmon (*Hucho hucho*)). Other fish may profit from warmer temperatures, for example carp (Cyprinidae) and exotic species (Niedermair *et al.*, 2007). The expected shifts in alpine water regimes — increased winter precipitation and run-off, shift of run-off peaks to earlier in the season and reduced summer precipitation and run-off, overall shorter duration of snow cover, glacier and permafrost melting — are likely to have a pronounced effect on other aquatic biodiversity as well. A recent study shows that the macroinvertebrate composition in streams changes as a consequence of lower flows and warmer stream temperatures (Brown *et al.*, 2007). Similarly, alpine lake ecosystems are sensitive to climate change (Parker *et al.*, 2008).

Photo: © Torsten Grothmann

Other severely threatened habitats include raised bogs and fens, which suffer particularly from the combined effects of climate change and eutrophication, specifically through atmospheric nutrient deposition.

Some macrofauna in the Alps, such as ibex (*Capra ibex*), alpine chough (*Pyrrhocorax graculus*), and rock partridge (*Alectoris graeca*) may experience a temporary enlargement of their habitat, due to warming. Other more isolated populations will be threatened, such as snow finch (*Montifringilla nivalis*), water pipit (*Athus spinoletta*) and ptarmigan (*Lagopus mutus*). Lower alpine altitudes will continue to be 'mediterraneanised', referring to the increased occurrence of Mediterranean species, such as green lizard (*Lacerta viridis*) and praying mantis (*Mantis religiosa*) (Niedermair *et al.*, 2007). In summary, there is no doubt that unique cold and high habitats will shrink, while other biogeographic zones will extend into the Alps. This will cause shifts in species distributions, some more in the spotlight — like the ones listed here — others less, such as a host of soil microbes and microfauna, invertebrates, lichens and mosses.

4.2.3 Adaptation options

Adaptation options for biodiversity conservation in the Alps fall in two broad categories:

- supporting autonomous adaptation of the organisms and ecosystems, for example by maintaining genetic diversity and removing migration barriers; and

- maintaining the original habitat and preventing or slowing down climatic and environmental changes, for example through physical glacier protection, subsidies paid to upland farmers in order to maintain traditional pastures or the re-establishment of riparian forests to buffer run-off extremes and maintain a unique landscape.

To support autonomous adaptation, populations need to be kept large enough to maintain genetic diversity. In the long-term planning of forest plantations, care should be taken to pick climatically suited varieties and species, accounting for future climates. Migration corridors can counteract negative fragmentation effects and promote species ability to adapt their distribution through migration. However, shifting the borders of nature reserves along with shifting distributions of target species will probably prove unfeasible because of political, legal and economic barriers (Schröter *et al.*, 2005).

Although flood protection is not the focus of this report, it is necessary to mention that flood protection and biodiversity conservation can go hand in hand. Renaturation of rivers and riparian systems can buffer run-off peaks, offer additional flood plains and habitat for rare ecological communities. The retention time of water in the landscape is also increased and will absorb some of the run-off variability over the year. So, this strategy of 'ecological flood protection' offers multiple benefits to many stakeholders (Niedermair *et al.* 2007). Furthermore, a continuum of brooks, creeks, rivers and streams needs to be re-established, with an eye to using river branches and abolishing or circumventing any barriers. Existing dams should plan for excess water to be released in times of need (Niedermair *et al.*, 2007).

Physical protection of glaciers and similar efforts can slow down habitat change and loss. Ultimately though, alpine biodiversity will change due to climate change. Since some climatic changes are inevitable, other stresses on the habitat, such as invasive species and eutrophication need to be minimised. These additional stresses also include loss of pastures to abandonment and afforestation. Maintaining traditional mountain farming will sustain valuable habitat and may help to offset climate change effects on alpine biodiversity (Theurillat and Guisan, 2001; Grabherr, 2006). Furthermore, this has multiple effects on upland ecosystem services, which benefit upland touristic value, as well as lowland regions.

Finally, biodiversity conservation and management in the Alps should continue to observe the operational guidelines of the Convention on Biological Diversity (CBD, 2008a). The creation of a functioning ecological network in the Alps, as initiated within the Ecological Continuum Project (from the Alpine Network of Protected Areas (ALPARC), World Wide Fund for Nature (WWF), International Scientific Committee on Research in the Alps (ISCAR) and Commission Internationale pour la Protection des Alpes (CIPRA)) or the Ecological Network Platform (from the Alpine Convention), can help to conserve the extraordinarily rich alpine biodiversity. However, the uncertain (climatic) future makes it especially necessary to continuously adapt methodologies and practices and maintain dialogue with all relevant actors within the human-environment system.

4.3 Households

4.3.1 Relevance

Household use accounts for 60–80 % of the public water supply across Europe (EEA, 2009). Due to the water richness of a great part of the Alps and neighbouring countries, usually only a small percentage of the potential drinking water resources is actually extracted, i.e. used (2–3 % for Germany, Switzerland and Austria, according to BGW, 2006, OcCC/ProClim, 2007 and BMLFUW, 2007a, respectively). Depending on the region, drinking water is obtained to a varying extent from groundwater, bank filtration, surface water (mostly artificial dams), lakes and springs. Cities and municipalities are usually in charge of their water supply, which is delivered by thousands of local and (supra-) regional water companies in a decentralised manner. In contrast, in remote mountainous areas, drinking water traditionally comes from private wells. Depending on the geology of the aquifer, for example karst, unconsolidated rock or bedrock with fissures, the reliability of these springs varies. Springs in karst regions react most rapidly to changes in precipitation (OcCC/ProClim, 2007) and are the most sensitive to pollution ([17]) due to lack of filtration pathways (see also case study Vienna's water mountains). However, water resources within and from the Alps generally provide an excellent water quality, which makes alpine water an appreciated resource outside the Alps

([17]) As a consequence of increasing extreme events but also possibly increased use of pesticides in agriculture, for example for biomass production, the risk of pollution might increase.

Photo: © European Environment Agency

(see Chapter 3). The main consumers of the water are the households of the 13 671 000 inhabitants within the area of the Alpine Convention (Tappheimer *et al.*, 2008); to a minor extent it is also used for agricultural irrigation purposes (Weber and Schild, 2007) and also in food-processing and other industries. In the Alps, urban waste water treatment has been improved significantly in recent decades. Due to the topography and the dispersed settlement structure, there is still a high share of decentralised sewage treatment in the Alps, serving around 20 % of the population. There are concerns about the types and maintenance of these installations (Bouffard, 2008).

4.3.2 Water-related effects of climate change

As a consequence of increasingly warmer temperatures and especially during dry spells, the consumption of water in households for drinking and personal hygiene and for outdoor activities such as gardening or use of private swimming pools can be expected to rise (EEA, 2009; EEA, 2007; OcCC/ProClim, 2007; IPCC, 2007). Generally, water demand will increase only modestly due to climate change, except during heat waves (EEA, 2009). Although generally there will be sufficient drinking water in the Alps, the rate of groundwater recharge will probably decrease during summer and autumn. As a consequence, supply from near surface and karst springs, especially from small watersheds, could vary seasonally or these springs could even run dry, as happened for example during the hot summer of 2003. In remote, small areas dependent on glacier ice melt, drinking water delivery could also collapse. Also, in the larger valleys, groundwater levels in aquifers could decline during summer and autumn, depending on the discharge regime of the river. On the other hand, in winter ground water recharge will probably increase due to more precipitation, particularly a higher share of rain (OcCC/ProClim, 2007).

Water quality will also be affected by climate change, with the potential for changes in the cost of water treatment. Thus, changes in flow volumes will alter residence times (time required to replace a water body's current volume of water with 'new' water) and dilution. A rise in water temperature will affect the rate of biogeochemical processes. An increase in algal blooms and in concentrations of bacteria and fungi may further lead to an impairment of the odour and taste of chlorinated drinking water and the occurrence of toxins (Anderson *et al.*, 2008). Especially under low-flow conditions, elevated water temperatures result in lower oxygen levels, which might cause the release of heavy metals and nutrients from sediments and other biochemical reactions affecting drinking water supply quality and infrastructure. The latter might also become more threatened by sinking ground water levels or clay shrinkage, resulting in leakage from pipes, etc. as seen for example in 2003 (Eisenreich *et al.*, 2005). Furthermore, a manifold increase in concentrations of heavy metals has been observed in several lakes in South Tyrol, threatening their use for the abstraction of drinking water. This phenomenon is attributed to the release of solutes from the ice of active rock glaciers in the catchment as a response to climate warming (Thies *et al.*, 2007; Larcher, 2007).

Increase in frequency and intensity of heavy precipitation events will lead to more overflow of untreated waste water from combined sewage systems or of storm water from separated sewage systems. Discharge of treated (or untreated) waste water or storm water overflow increases the concentration of nutrients and pollutants in the receiving water bodies, with negative impacts on water quality especially under low-flow conditions.

4.3.3 Adaptation options

Measures to increase the reliability of drinking water supply include the protection of drinking water generation and resources, expansion of drinking water networks, the use of surface, rain and grey water as well as water-saving practices. The selection of the specific strategy will depend on setting-specific cost–benefit analyses (Prettenthaler *et al.*, 2006). As a consequence of the dry year of 2003 and extreme weather conditions during the past years, connections to public water supply have increased in areas serviced before by private wells such as in (eastern) Austria (Eisenreich *et al.*, 2005), increasing the demand for water companies. Also, in Switzerland water networks are being extended to increase the security of supply, although apparently not because of the influence of climate change; in rural areas, for example, water network infrastructure is adjusted to meet fire-fighting requirements (Ecoplan/Sigmaplan, 2007). On the demand side, measures to increase the efficiency of water use, for example water pricing, leakage reduction, water re-use, more efficient irrigation, more efficient water-use appliances (Anderson *et al.*, 2008; EEA, 2009) as well as the reduction of personal daily water use (OcCC/ProClim, 2007) represent a considerable water saving potential (Ecologic, 2007). Water quality can be protected by improved waste water treatment and extension of separate sewage systems, in combination with increased storm water infiltration options.

4.4 Forestry

4.4.1 Relevance

In the Alps, forests cover around 43 % of the land surface, which constitutes a total area of 7.5 million ha. The forest stand is composed of 50 % coniferous, 23 % deciduous and 27 % mixed forests. The Alps provide a total of 1.5 billion m^3 of timber (on average between 290 and 360 m^3/ha) (CIPRA, 2001). The annual growth of timber amounts around to 37 million m^3 but approximately 75 % of the increase is harvested every year. Wood is used to produce a diverse range of products and services that society relies upon for various activities. For example the traditional use of timber and other woody biomass as fuel means that it is still a significant energy source (Anderson *et al.*, 2008). Beyond supporting timber-producing industries, forests serve a multitude of functions, for example they are a carbon sink/source, maintain the characteristic alpine landscapes and provide recreational areas.

Due to climate change, forest cover in the Alps is expected to increase in the future. This is because higher temperatures and land abandonment will in turn raise the above-ground carbon storage capacity. With regard to drinking water, the filtration functions of forests are important for securing water quality.

4.4.2 Water-related effects of climate change

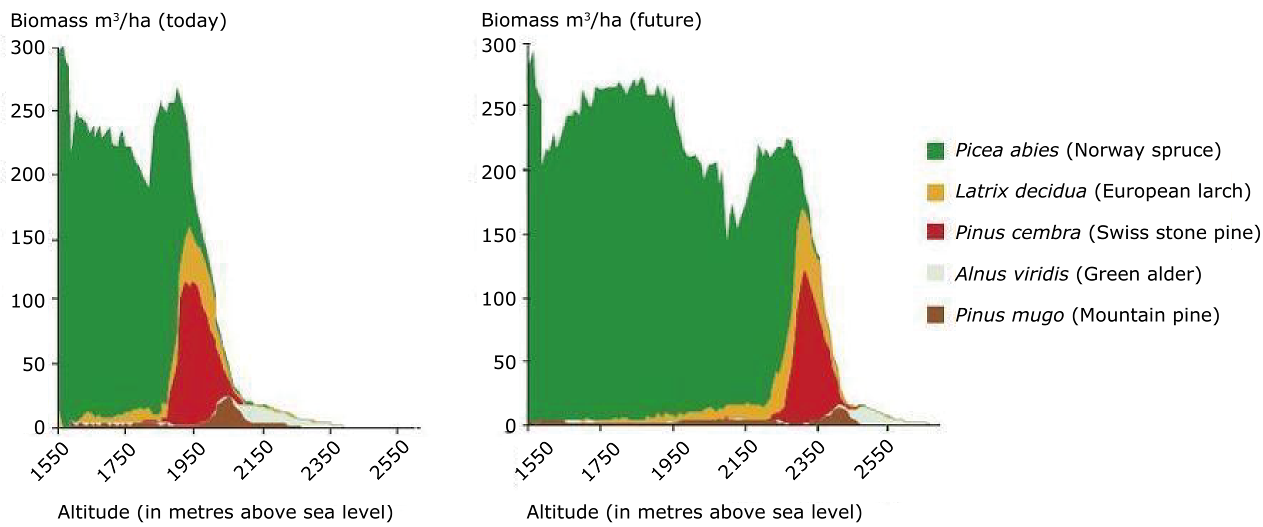
Tree growth and the health of forests are crucially dependent not only on temperature, but also on the amount and distribution of precipitation. The effects of climate change may alter a range of forest services and functions, but the magnitude and direction of these impacts cannot yet be predicted with confidence (IPCC, 2007; Roetzer, 2005). In general, depending on stand and site conditions, changes can be expected in growth of timber and non-timber forest products as well as in decomposition rates, soil and water protection activities, land use patterns and other ecological processes (for example carbon and water cycles). Forests also release large amounts of water into the air through evapotranspiration ([18]). With increasing temperatures, the water demand by plants and soils can be expected to increase (Zebisch *et al.*, 2005).

It can be expected that an increase in CO_2 and an extended vegetative period will raise the wood yield, given sufficient provision of water and

Photo: © Torsten Grothmann

([18]) Evapotranspiration is a term used to describe the sum of evaporation (from sources such as soil, canopy interception and water bodies) and plant transpiration.

Figure 4.4 Impacts of climate change on landscape structure in Dischmatal (Graubünden, Switzerland) in an ecosystem model



Source: Körner *et al.*, 2005, in BMU, 2007a.

nutrients. A study conducted in Austria showed that the length of the growing season in the alpine area increased by 25 days between 1961 and 1990, resulting in an improvement in net primary production of Norway spruce by 5–10 % (Hasenauer *et al.*, 1998). A more complex effect could be the possible reallocation of biomass growth between different parts of the tree, e.g. increasing young shoots to the expense of increasing trunk diameter. Both factors could alter the supply and availability of wood products — hence their pricing — with impacts on the market.

Further possible direct effects of climate change on forests include — as a worst case scenario — rapid forest dieback events and decreased tree vitality triggered by drought. Forests already suffering from drought will face further decrease in productivity. In low-elevation forests of the Alps, secondary coniferous forests (mainly of Norway spruce) may suffer from increased drought and susceptibility to infestation by insects and disease organisms, which in turn might be additionally favoured by a warmer climate (Lexer *et al.*, 2001). Furthermore, for several insect species a climate-induced migration northward and upward in altitude in northern temperate forests has been observed as well as changes in the seasonal phenology of insects (Battisti, 2008).

Taking a long-term view, the more frequent occurrence of hot and dry years could result in a change of tree composition and diversity of forests (BMU, 2007a). A comparison of tree composition in today's climate and the future climate for a region in the Swiss Alps shows clearly a replacement of sensitive tree species and the shift in tree line (Figure 4.4). This in turn is likely to alter several services like the water-holding capacity of slope systems and thus alter the hazard prevention capability (soil erosion, landslides, etc.) (Fuhrer *et al.*, 2006; Gehrig-Fasel *et al.*, 2007). In reverse, more frequent heavy precipitation events in the alpine region may significantly increase the risk of damage from flooding, erosion, debris flow or landslides.

Indirectly, climate warming affects forest vegetation by increasing forest fires and windstorms, which lead to a short-term loss of timber and, consequently, insect outbreaks (Wohlgemuth *et al.*, 2006). Experience gained from the storms 'Vivian' in 1990 and 'Lothar' in 1999, which affected large areas of central Europe, shows that monocultures of coniferous species are more sensitive than those of deciduous species (Fuhrer *et al.*, 2006). Stands with a large proportion of coniferous trees and high average breast-height diameter seem to be most vulnerable (Dobbertin *et al.*, 2002).

4.4.3 Adaptation options

Compared to other sectors, decisions taken today in forestry (for example tree species choice) will remain mostly irreversible for decades to come, and the capacity of this sector to adapt has to be seen in a long-term perspective. Forest management will influence the degree to which water resources can be maintained or enhanced (Anderson *et al.*, 2008). Afforestation and sustainable forest management can improve the water storage capacity of soils to make them act as a buffer during intense precipitation events (Leipprand *et al.*, 2007). In addition, sustainable forest management can protect soil and land against detrimental impacts of flooding and erosion. Conversely, it has been observed that deforestation and forest harvesting adversely affect the quality of water in streams at local level (Giller and O'Halloran, 2004).

In general, forest management needs to take the changing climatic conditions (for example higher temperature, modified rainfall pattern) into account and should aim to reduce as many ancillary stresses on the forest resources as possible (IPCC, 2007). By definition, locally adapted populations have a higher level of robustness than non-locally adapted populations. For this reason, increasing the proportion of locally indigenous tree species and diversification of the vertical structure can be seen as suitable adaptation options for the forestry sector. Since climate change will probably proceed faster than natural forest renewal, the introduction of provenance from warmer and drier climates might be an effective strategy. In addition, mixed stands and forests with high genetic diversity are less sensitive than coniferous forests, since they can better adapt to climate change (Zebisch *et al.*, 2005).

Existing studies show that more research is needed to develop appropriate adaptation measures and that the dissemination of information to foresters, forest owners and decision-makers is important to encourage implementation of adaptive measures (Lindner and Kolström, 2009; Weis *et al.*, 2008).

4.5 Agriculture

4.5.1 Relevance

In the Alps, agriculture is a characteristic form of land use which shapes the mountainous landscape in a unique way. One quarter of the Alps, 4.5 million ha, is potential agricultural land, composed of 83.3 % grassland, 12.6 % arable land ([19]), 3.2 % permanent crop and 0.8 % other cultivated land (CIPRA, 2001). In 2001, 482 248 farms were counted in the Alps. 5 % of the labour force works in the agriculture sector, but two-thirds of the farms are managed part-time (CIPRA, 2001). The average size of the farms is small in comparison to those in non-alpine regions, but farm size can be expected to grow in the future as a result of socio-economic factors (for example alternation of generations).

Productivity of agricultural systems is critically dependent on many factors, including climatic conditions, the temporal and spatial distribution of precipitation and evaporation, and the availability of freshwater resources for irrigation (IPCC, 2008). The agriculture sector is one of the main water users in Europe, using 24 % of the total abstracted water for the period 1997 to 2005 (EEA, 2009). Most irrigation is concentrated in southern Europe, but there is no data available for the Alps specifically.

In the dry valley of Valais (Swiss Alps) hill irrigation for meadows, vineyards and orchards has a long tradition (Reynard, 2002), but in this and similar areas increased water demand by agriculture due to climate change will reduce water supply for other sectors (North *et al.*, 2007). For example in Switzerland in 2003, irrigation to mitigate drought led to low river run-off and conflicts between farmers and water protection concerns (BUWAL *et al.*, 2004). In the event of water scarcity, use as drinking water would have priority over use in agriculture (IPCC, 2007).

4.5.2 Water-related effects of climate change

Global warming is expected to affect agriculture very differently depending on the geographical region. In general, the effects of climate change on agricultural productivity depend on the interactions between changes in CO_2 concentration, the length of the growing season, water availability, and pests and diseases. As yet there is little information available about the effects on agriculture in the Alps.

In northern Europe and at higher altitudes, an increase in temperature and sufficient water supply may prolong the vegetative period resulting in a short-term increase in agricultural yield (BMU, 2007a; Schaller and Weigel, 2007). Furthermore, the increase in atmospheric CO_2 levels will have a fertilising effect on crop growth for certain species and on grassland productivity (Long *et al.*, 2006 in Anderson, 2008; Fuhrer, *et al.*, 2006). The increase in productivity is likely to be largest for sites with

([19]) Output from arable farming is expected to increase due to an increase in biomass production.

favourable edaphic conditions, such as the bottom of mountain valleys, whereas changes may be much smaller in marginal areas (Behringer *et al.*, 2000). In the long term, there is the risk of yields declining in the Alps due to water stress (OcCC/ProClim, 2007).

Global warming is likely to increase the frequency and intensity of extreme events, like drought or heavy rain, which could seriously impact crop yield and permanent grassland. For example, the heat wave in 2003 severely affected farmers in Switzerland causing harvest losses and a reduction of the net income by 11 % (BMU, 2007b). More frequent drought induces not only decreased productivity, but also declining quality. In permanent grassland, drought might cause formation of gaps in the sward, which can be colonised by weeds and in turn have negative implications for animal nutrition (Fuhrer *et al.*, 2006). In contrast, heavy precipitation results in a greater loss of topsoil by erosion (EC — DG Agriculture and Rural Development, 2007) and can cause crop damage through soil waterlogging (Fuhrer *et al.*, 2006).

Impacts can also be expected from the likely increase in the spatial distribution and intensity of existing pests, diseases, and weeds due to higher temperatures and humidity (FAO, 2007). Furthermore, higher temperatures result in greater water consumption by livestock and more frequent heat stress for the animals (Leipprand *et al.*, 2007; Anderson *et al.*, 2008; Olesen *et al.*, 2005). This in turn causes declines in physical activity, including feed uptake. In the French Alps, cattle farmers faced new problems when springs dried up during the summer of 2003. To guarantee the supply of water for animals, farmers had to pump water uphill.

Photo: © Canton Valais (François Perraudin)

4.5.3 *Adaptation options*

Farmers have always adapted their farming practices in the short term to changing environmental conditions, for example by altering cropping patterns (Iglesias *et al.*, 2007). Measures to adapt to climate change can be taken at different levels (modified according to Leipprand *et al.*, 2007, and BMU, 2007a):

- at farm level adjustments may be realised, for example by altering cultivation intensity, crop choice (for example use of more resistant varieties to reduce dependence on irrigation or to increase water availability), sowing dates, or diversifying production to increase flexibility, as well as building buffer zones to reduce water run-off. Furthermore, traditional extensive grazing under shepherd supervision (to prevent increased risk of erosions and landslides, due to unsupervised livestock rambling on steep unstable slopes) could be a solution with several benefits: increased water harvest, increased landscape and species diversity, increased protection of slopes against erosions and landslides, enhanced cultural services, benefiting quality of life in the region. The Catskill watershed, which provides New York City with its drinking water, is a well-known example of downstream users successfully paying upstream farmers to maintain a diverse, extensively grazed mountain landscape to maximise water quality and harvest (Daily and Ellison, 2002);

- at water management level, more efficient water use and reduced water loss may be achieved by appropriate/sustainable land use (for example conservation tillage, mulching) and irrigation management (for example adjust time and amount of water according to plant needs). Water pricing according to consumption would be an effective economic instrument at this level. Furthermore, small-scale water conservation measures should be discussed, such as collecting water from farm buildings and constructing on-farm reservoirs to supply water for agricultural activities (Anderson *et al.*, 2008);

- technological measures could increase the efficiencies of irrigation systems (for example night-time irrigation), technical improvement of varieties as well as increased cleaning of dirty/saline water pipes. In general, efficiency gains of up to 50 % in water use per unit area are possible by switching irrigation technologies from gravity to drip or sprinkler-feed systems (Anderson *et al.*, 2008). Furthermore, technical measures to decrease non-point water pollution could be implemented;

- education and advice are needed to ensure efficient adaptation at farm and regional scales;

- improved insurance systems are necessary to protect farmers from the economic impacts of flood or drought damage. One alternative is a comprehensive crop insurance scheme: in the event of loss, farmers would be legally entitled to be compensated for the insured yield amount for their particular farm and payment would be made immediately after the loss has occurred (Munich Re Group, 2007);

- at national and EU level, possible options might be the implementation and enforcement of water saving regulations and a changing subsidies system related to irrigated crops. Rural development funding, provided under the second pillar of the Common Agricultural Policy (CAP), could be used to directly support measures aimed at adaptation, such as the development of water-efficient technologies or the production of water-extensive crops (EEA, 2009).

4.6 Tourism

4.6.1 Relevance

The Alps are — after the Mediterranean coast — the second most favoured holiday destination in Europe (EEA, 2003), which means that more than 60 million overnight guests (which is four times the local population) frequent the Alps every year. In 1995, 370 million overnight stays were registered and 4.7 million bed-places were available (CIPRA, 1998). According to the OECD, the tourism sector provides 10–12 % of jobs in the Alps (OECD, 2007). Summer tourism has stagnated since the early 1970s whereas winter tourism has expanded significantly, compensating for the weak tourist numbers during summer. With an annual turnover of 50 billion EUR, the winter tourism industry contributes significantly to the Alp's economy (OECD, 2007). The Alps are home to more than 600 ski resorts and 10 000 ski installations, 85 % of which are in France, Switzerland, Austria and Italy.

Tourism is a rapidly growing sector with the potential for negative impacts on the environment, in particular on water quantity and quality: water consumption by tourists tends to be much higher than that of local residents in holiday destinations leading to serious problems in dry summers with low water regimes (Leipprand *et al.*, 2007). In winter, artificial snow-making is currently the most widespread strategy to extend and supplement natural snow cover and secure winter tourism (Elsasser and Bürki, 2002). In Austria, for example, 50 % of the total skiable terrain is equipped with snow-making facilities and in the winter season 2007/2008, ski operators spent 127 million EUR on new snow-making equipment (WKO Austria, 2007). Artificial snow-making is not only very costly, but also has knock-on effects such as increased water consumption and energy demand or ecological damage, which may lead to negative externalities. This includes potential disturbance of the hydrological cycle for habitats of high conservation value such as bogs, fens and wetlands at high altitude. To serve all 28 500 ha of ski runs that use artificial snow-making equipment (which is 0.15 % of the total alpine area), 17–43 million m³ of additional water supply would be needed per year (Teich *et al.*, 2007). For artificial snow production, water is taken from natural lakes, artificial water reservoirs, rivers or groundwater in a period of the year when the water level is already low. During spring snow melt, in turn, a greater amount of water that was stored during winter comes down from the ski runs, which potentially contributes to flood risks (Teich *et al.*, 2007). Due to future climate change effects, conflicts between drinking water supply, energy production, agriculture and artificial snow production can be expected to increase.

Table 4.1 Water consumption of snow-making system in Garmisch-Partenkirchen, Germany under ambient temperature

	– 4 °C	– 7 °C	– 10 °C
Snow capacity per snow gun	23 m³/h	34 m³/h	45 m³/h
Water use per snow gun	11 m³/h	15 m³/h	18 m³/h
Operating time	120 h	81 h	61 h
Total water consumption	5 261 m³	4 853 m³	4 400 m³

Source: OECD, 2007.

4.6.2 Water-related effects of climate change

As an effect of climate change, warmer and drier summers may increase the number of tourists choosing to holiday in the Alps instead of the Mediterranean regions, which may experience less favoured temperatures (Müller and Weber, 2008). Additionally, climate change will increase water temperatures in alpine lakes, which could open up new opportunities for summer tourism. One the other hand, it will also influence the water regime of rivers and lakes, which might adversely affect water-bound activities like rafting or fishing (Elsasser and Bürki, 2005). Other factors, for example glacier retreat due to climate change, may also mean the Alps will become less attractive as a tourist destination. The ongoing melting of permafrost increases the risk of landslides and rock fall. Plus there is the risk of mountain cableway stations, lift masts and other buildings in permafrost soil becoming unstable (Bürki *et al.* 2003; Behm *et al.*, 2006).

Winter tourism is highly dependent on snow security; to be economically successful, a skiing area requires a minimum of 100 days with sufficient snow (König and Abegg, 1997). In the alpine countries, areas at altitudes higher than 1 200–1 300 m usually fulfil this criterion, although it may differ from region to region depending on regional effects, like inversion and wind. According to the OECD, a temperature increase of 1 °C will move the snowline upwards by 150 m, which will shorten the winter season (OECD, 2007). Today, about 599 out of the 666 (or 90 %) alpine ski resorts in Austria, France, Germany, Italy and Switzerland can be considered as naturally snow-reliable. This number would drop to 500 with a 1 °C warming and to 404 with a 2 °C warming of the global mean air temperature (OECD, 2007).

4.6.3 Adaptation options

In general, tourism has large potential for adapting to the changing climatic situation, for example by developing new tourism offers and economic diversification (also involving other economic sectors such as agriculture). In relation to water resources, adaptation efforts are needed at all levels (for example government, tourism operator). A range of measures can be taken in order to mitigate negative impacts on water resources. Leipprand *et al.* (2007) summarise the following key issues:

- a diversification of tourism products towards activities that are less dependent on water resources;

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- tourists should be informed about what they can do to help save water (for example they should choose a hotel with an eco-label).

The promotion of the idea of sustainable tourism development would reduce conflicts between different users. More specifically, tourist operators can contribute to mitigating negative impacts by, for example, introducing water-saving strategies and techniques, water recycling (in accommodation, catering facilities, golf courses, etc.) and staff training (BMU, 2007a).

In expectation of climate change, stakeholders in winter sport areas are already trying to find new solutions for tourism (Disch and Reppe, 2007). According to the OECD (2007), the range of adaptation practices can be divided into behavioural (withdrawal from ski tourism to all-year tourism) and technological options (such as landscaping and slope development, moving to higher altitudes, glacier skiing and artificial snow-making).

Artificial snow-making will probably remain the dominant adaptation strategy in the future. The rise in temperature will on the one hand shorten the time within which the production of artificial snow is technically feasible (based on current technology).

On the other hand, higher temperatures cause lower snow capacity and therefore longer operating time, which in turn leads to higher total water consumption (Table 4.1).

It should be noted that snow-making as a stand-alone adaptation measure might in the long term be regarded as a clear example of maladaptation as it contributes further to global warming (by using energy) and to additional environmental impacts (by using water). A study conducted for a winter sport region in Austria showed that after 2050, snow-making (using current technology) cannot ensure winter holidays, as by then, statistically, there will be several weeks without snowfall every fifth year (Formayer, 2007). And even where snow-making is climatically feasible and water supply can be secured, the additional costs associated with increasing snow-making volumes and increasing cost for further technical equipment may not be economically feasible for some ski area operators (OECD, 2007).

4.7 Energy

4.7.1 Relevance

The most important energy sources of the Alps are hydropower and biomass. The installed hydropower capacity in the Alps is estimated to vary between more than 400 MW in Germany and Slovenia, more than 2 900 MW in France, Italy and Austria and more than 11 000 MW in Switzerland (CIPRA, 2001). Hydropower is especially important for supplying peak demands (CIPRA, 2001; BFE, 2007a). The significance of biomass as an energy source in the alpine countries varies considerably, with less relevance in Germany and a higher and strongly increasing relevance in Austria (Eurostat, 2008a; BMLFUW, 2007b). In Switzerland biomass consumption is expected to retain a small share of energy supply in the next decades (BFE, 2007a). Wood is particularly important as a fuel in the alpine area (CIPRA, 2001). Analysed on a national basis, in France, Germany and Slovenia thermal power stations have a larger role than hydropower or bioenergy (Eurostat, 2008a).

The water demand of the energy sector is high and generally exceeds the demand of other industrial sectors (Létard *et al.*, 2004). The most water-intensive energy sources are hydropower and thermal power. Plants producing energy from biomass also require a relatively large amount of water (de Fraiture *et al.*, 2007), but water use for biomass production has not yet been assessed for the Alps. Large amounts of water are evaporated during the cooling process of thermal power stations. The water amount varies considerably between the diverse technologies applied. In Germany thermal power stations are the main water users, with a share of 64 % of total water use (BfG, 2006). In the Rhone basin about 69 % and in northern Italy 13 % of the water abstracted is used for cooling purposes during electricity production (DG Environment, 2007).

4.7.2 Water-related effects of climate change

The energy sector is generally influenced more by factors such as economic growth or technology development than by climate change. Climate change is considered to have a larger impact on energy production than on other sectors of industry (OcCC/ProClim, 2007; Wilbanks *et al.*, 2007), since it will alter both the energy demand and water availability. In Switzerland and Austria the energy demand for heating will decrease substantially, whereas the demand for cooling will increase (BFE, 2007a; Prettenthaler *et al.*, 2007). In the long term, the latter might offset the reduction gained from less heating (Ecoplan/Sigmaplan, 2007). This will lead to a shift in demand from energy in the form of heat towards electricity (BFE, 2007a). Additionally, energy suppliers will have to cope with an increasing variability of demand (EDF, 2005).

The main challenges for thermal power production during droughts are the smaller temperature difference between the water extracted for cooling and the water returned, which reduces production potential, as well as restrictions concerning minimum levels of river flow rates after water abstraction and maximum water temperatures. An upward trend in extreme temperatures of river water has already been observed for the Rhone and Rhine rivers (Huguet *et al.*, 2008; Müller *et al.*, 2007) and an increase in average annual water temperature has been detected for the rivers Danube and Rhine in the past decades (EEA, 2008). In Switzerland, no fundamental production losses due to climate change are expected for thermal power stations over the coming years (BFE, 2007a), but extreme drought events can have seasonal impacts, which have to be taken into account in performance considerations (BFE, 2007a; OcCC/ProClim, 2007). Such an event took place in the exceptionally hot summer in Europe in 2003, when thermal power production fell in Switzerland by 25 % for two months (OcCC/ProClim, 2007); reductions have also been reported in France and Germany (DGEMP, 2003; Lönker, 2003).

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In the short term, hydropower production could benefit from additional water from the melting glaciers. In the long term, however, considerable changes for hydropower production are expected (BFE, 2007a; OcCC/ProClim, 2007). Switzerland might be more negatively affected than other alpine countries, which show ambivalent hydropower potential until 2080 under climate change (Lehner *et al.*, 2005). Hydropower production in Switzerland is projected to fall by 7 % by 2035 (BFE, 2007a), by 11 % by 2050 and by 22 % by 2100 (Ecoplan/Sigmaplan, 2007) compared to 1961–1990. The impacts can be more pronounced for some power stations. For example, annual hydropower production at the Mauvoisin Dam in Switzerland may drop 36 % by 2070–2099 compared to 1961–1990 (Schaefli *et al.*, 2007). A preliminary study on two basins with hydropower production in the Italian Alps also suggests a reduction in run-off in the future (Barontini *et al.*, 2006). A market analysis shows that peak energy demand could still be covered during heat waves in Switzerland in the future because of large water reservoirs and import possibilities, but ensuring base load supply could lead to strong impacts on the water volume in reservoirs and thus to insecurities in supply (BFE, 2007a). Hydropower production will also be affected by seasonal changes in water availability. With an expected general increase in run-off in winter and a decrease in summer, climate change would buffer seasonal variations and thus can increase the flexibility of plant operators (OcCC/ProClim, 2007). In some regions however, negative effects on production in summer and positive effects in winter are expected.

There is very little information available on the impacts of drought upon reduced biomass production for energy purposes (Eisenreich *et al.*, 2005). On one hand, biomass production consumes large quantities of water and is thus negatively affected by drought events. On the other hand, the expected shifting of vegetation belts to higher elevations, and higher CO_2 concentrations, could potentially lead to an increase in biomass production (Ecoplan/Sigmaplan, 2007). A strong increase in wood biomass potential is expected for Switzerland (Ecoplan/Sigmaplan, 2007; BFE, 2007b) and Austria (BFW, 2009). Nevertheless, in Switzerland the impacts of climate change on biomass production are not yet clear (BFE, 2007a). Model analyses for Europe until 2030 show an increase of 17 % in water consumption by plants used for biofuel production but an increase of only 1 % in irrigation withdrawals compared to 2005 (de Fraiture *et al.*, 2007).

There is a need for further research into the impact of climate change on the energy sector. Results from recent studies on hydropower indicate future production losses due to decreasing river flows, whereas in the past flow rates were predicted to increase (Hänggi and Plattner, 2007). There are very few recent case studies on power plants that consider climate changes as well as variations in demand. There are also hardly any studies that deal with the impact of water scarcity on other energy sources such as biomass.

4.7.3 Adaptation options

There is large potential for adaptation in the energy sector. Enforcing interconnectedness of energy systems, including across country borders, could increase the flexibility of the energy sector (Arnell *et al.*, 2005; BfG, 2006). By reducing the risk of production losses during extreme events, insurance systems will become more important (Ecoplan/Sigmaplan, 2007; Prettenthaler *et al.*, 2006). To meet the challenges of increasing changes in energy demand and supply, an effective load management, such as reducing peak demand in periods of short supply, is essential. This could be achieved by applying both load and climate condition forecasting models (BMU, 2007a). Various technical adaptation options exist for thermal power plants. Many of the older plants in Europe are expected to be replaced within the next 30 years (EEA, 2005). The new plants will operate with more efficient looped water systems or even dry cooling systems. Thermal power stations in coastal areas do not have to cope with water temperature restrictions and are thus less sensitive to droughts than stations dependent on river water (Létard *et al.*, 2004). To a certain extent they could thus alleviate the impact of summer droughts for countries with access to the sea, when plants along rivers are at risk of shutting down. Maintenance work at power plants is usually carried out during the summer months, when energy demand is low, which aggravated the energy shortages in 2003 (Létard *et al.* 2004; BfG, 2006). A seasonal change in the maintenance schedule could therefore help to adapt to summer droughts. For hydropower plants, the impact of low water supply could be reduced by applying turbines that use lower nominal power (BMU, 2007a). The main adaptation option for saving water in biomass production is the use of agricultural technologies (Ecologic, 2007). In addition to these adaptation options, a reduction in the energy demand or a shift towards less water-consumptive energy sources, such as solar or wind power, could reduce the sensitivity of the energy sector to diminished water availability.

4.8 Industry

4.8.1 Relevance

Industry generally still plays a larger role in alpine regions than in non-alpine regions, due to differences in transition rates from the secondary to the tertiary economic sector (i.e. from the transformation of raw or intermediate materials into goods to the provision of services to consumers and businesses; Bätzing, 2003). In areas neighbouring the Alps, the industrial sector dominates parts of Baden-Württemberg and northern Italy, whereas regions like Vienna, Provence-Alpes-Côte d'Azur and Liguria are dominated by the service sector. Water consumption varies greatly between industries. There is very little specific information on this (Flörke and Alcamo, 2004), but some use large quantities of water, especially the leather, textile, paper, chemistry and food processing industries (Ecologic, 2007; Egger, 2007; Dalla-Via *et al.*, 2006). In the Rhone basin 6 % of the water abstracted is used for industrial purposes and in river basins in northern Italy the figure is 20 % (DG Environment, 2007).

4.8.2 Water-related effects of climate change

The impact of water scarcity on industry is generally low compared to other sectors like agriculture or river navigation. The influence of other economic and social factors is higher than that of climatic changes (Wilbanks *et al.*, 2007). The impact of water scarcity on industries in the Alps has only been analysed marginally, since water availability is generally considered to be high.

Some conclusions can be drawn from countries and regions adjacent to the Alps. For example a survey of water-intensive industries in the Danube basin showed that about 3 % of the industries reported production losses in 2003 due to the exceptionally hot summer. Further, 15–25 % of these industries expect an increasing risk with regard to water availability in the future (Egger, 2007). In France the costs of droughts for the industrial sector amounted to about 300 million EUR in 2003 and 270 million EUR in 2005 (DG Environment, 2007). An analysis for Eastern Styria (Austria) calculated a production loss of 105 million EUR in the event of a two-week breakdown due to water shortages, with the metal and food production industries affected the most. Since many industries rely on water as an essential input factor, long-term shortages will lead to much higher losses (Dalla-Via *et al.*, 2006). The insurance industry could benefit from growing demand if risks are anticipated (Wilbanks *et al.*, 2007).

Cross-sectoral competition could arise due to waste water generated in industries, which could threaten water quality of streams in periods of drought due to insufficient dilution (see Figure 4.2). Industrial processes can release toxic substances, including POPs (persistent organic pollutants) such as PCBs (polychlorinated biphenyls) and HCHs (hexachlorobenzene), directly into water bodies or indirectly after atmospheric transport and deposition. Due to long-range atmospheric transport of intermediate volatile substances like PCBs and HCHs, they also affect remote areas. They can enter the food chain where they bioaccumulate and threaten aquatic and terrestrial organisms. Climate change aspects (for example temperature increase, variations in rainfall, wind patterns and dust deposition) affect the distribution and mobility of toxic substances in freshwater systems. Lakes in cold regions, for example at high altitudes, are especially vulnerable as intermediate volatile compounds released from warm lowland environments are transported to high elevation, condense and precipitate at lower temperatures, leading to a net uptake of toxic compounds in fish and lake sediments. An increase in temperature may lead to an increase in the transport of toxic substances to colder environments and probably also to an increase in the net uptake within the food chain (Euro-limpacs, 2008).

4.8.3 Adaptation options

In many sectors of industry adaptation towards efficiency in water use is generally high, and therefore economic growth is not necessarily dependent on water availability (Edwards *et al.*, 2005). Adaptation possibilities can range from new technologies or business models, like the incorporation of climate risk management into business strategies, to relocating activities

(Wilbanks *et al.*, 2007). Water-saving efforts, for example through (waste) water recycling or change of industrial processes, represent the most important adaptation options. The water-saving potential of the European industry sector until 2030 is estimated to amount to 34 % of water use in 2001 (Flörke and Alcamo, 2004). Estimates for different industry types generally vary from 30 to 70 % (Ecologic, 2007), also dependent on their level of modernisation. Industrial companies in eastern Styria estimated their water-saving potential at about 5–10 %. Measures like investments in new water pipelines also seem valid adaptation options, since costs are lower than calculated potential production losses without adaptation (Dalla-Via *et al.*, 2006).

4.9 River navigation

4.9.1 Relevance

The most important rivers in the Alps for navigation are the Rhine, Danube, Po and Rhone. In Germany inland waterways' share of freight transport performance in 2006 was 12 %, in France and Austria it is about 3 %. In Italy and Slovenia this sector has a minor role (Eurostat, 2008b). In Switzerland transportation via the Rhine accounted for approximately 9 % of the country's external trade in 2006 (Ports of Switzerland, 2007). In Germany 84 % of the goods transported on inland waterways in 2008 were shipped via the Rhine (DESTATIS, 2008). River navigation is not a direct cause of water shortages as it is not a water consumer like agriculture or industry. Nevertheless, it alters hydrologic regimes indirectly through locks and other river regulations to ensure navigability.

4.9.2 Water-related effects of climate change

Inland navigation is mainly influenced by water depth. Low river discharges will therefore negatively impact transportation by reducing loading and as a consequence increasing transport prices, and will negatively affect competitiveness (Ecologic, 2007). Generally, the expected increased variability of the hydrological system will lead to more unstable conditions for navigation and could thus threaten the reliability of riverine transport (Ecologic, 2007). Inland navigation is also influenced by ice cover. An increase in ice-free conditions has already been observed for several rivers in the Northern hemisphere (Lemke *et al.*, 2007), a further increase could improve river navigation conditions (PIANC, 2008; BMU 2007a).

There is little information available on future climate change impacts on river navigation in the Alps. Some information is available about impacts on sections of major rivers outside the Alps, where alpine discharges are essential for navigation. At the Rhine's gauge in Cologne, the crucial period of low flows has already shifted from October to September (BMVBS, 2007). In the future an increase in winter run-off and a decrease of summer flow is expected for alpine rivers due to less water stored in form of snow. The buffer function of alpine water flows will thus decrease, leading to stronger seasonality of river discharges further downstream. This could have negative impacts on the river navigation sector (BMVBS, 2007). Low water conditions in the Rhine have nevertheless decreased during the past decades in Germany, with the exception of the recent years 2003 and 2006, which had unusually warm summers (BMVBS, 2007).

In general, river discharges in summer are expected to decrease in future in Europe (BMVBS, 2007), but extremely low water conditions, which are the main threat for the navigation sector, are difficult to analyse. The average number of days per year with critical water depth for navigation on the Rhine may increase from currently 19 to 26–34 days by the year 2050 (Middelkoop *et al.*, 2001). An insight into the potential future situation is also possible by analysing low-flow conditions during the exceptionally hot summer in 2003. Transport volume decreased by about 5 % in Germany, larger ships being more affected than smaller ones (BfG, 2006). The estimated loss for the Rhine navigation market in 2003 was about 91 million EUR (Jonkeren *et al.*, 2007). A fictitious coal-fired power plant near Kaub in Germany dependent on transport of coal by river would have required 90 % more ships in 2003 than in normal years due to less loading capacity (Scholten *et al.*, 2007). The railways could not compensate for the impairment in transportation capacity in 2003 (BfG, 2006). Also, ports on the Danube River reported losses of several million euros during 2003 (Eisenreich *et al.*, 2005). Shipping companies can cope economically with short periods of low water levels and decreasing freight capacities by contracts stipulating freight surcharges during these events. But longer periods of drought could have consequences that have not yet been adequately assessed (BfG, 2006).

4.9.3 Adaptation options

Sound adaptation strategies will have to be found to avoid compensating for reduced river transportation during drought periods by shifting to other transport modes that are potentially more harmful to the climate, such as road transport (OcCC/ProClim, 2007). The two obvious ways of adapting to low water conditions are adapting the waterways themselves or altering ship design. Improving the channel conditions to ensure navigability at lower water levels could partly alleviate the expected problems (Middelkoop *et al.*, 2001) but can lead to ecological conflicts. Ships with less draught have more advantages under low water conditions. Some advances in ship construction have been made to reduce draught and improve manoeuvrability, for example the 'Futura carrier' funded by the BMU or 'INBAT', an EU 5th FP project (VBD, 2005). Innovative lightweight materials could further reduce weight, and thus draught, for example a combination of an elastomer and steel (I.Mar.EST/IESIS, 2005). However, the general trend is towards larger ships with more draught (BMVBS, 2007). In addition to these long-term adaptation options, better seasonal discharge predictions at waterway level could help the sector to adjust in the short term (OcCC/ProClim, 2007). Furthermore, avoidance of redundant transportation, changes in industrial production leading to lower transport requirements or shifting transport towards the season with high river discharges, if possible, could reduce the pressure on the navigation sector during months of low water flows.

Photo: © European Environment Agency

5 The regional perspective

5.1 Overview and methodology of regional case studies

Summary

The 'case studies' part of this report presents the results of an analysis of water resource issues (shortages, quality) under the pressure of climate change impacts, and activities to adapt to these problems in various water-sensitive regions of the Alps. The case study regions have not been selected to be representative of the Alps; rather, the case studies served to explore and illustrate key issues related to water resource issues and their management under the conditions of climate change. They were carried out for Lavant valley and Vienna in Austria, the Valais in Switzerland, South Tyrol in Italy, the Savoy region in France and the River Soča in Slovenia and Italy. Besides detailed literature analyses for the different regions, essential parts of the case studies were interviews with stakeholders who were directly involved in the adaptation activities or had knowledge about them. A workshop involving experts on climate change impacts, water resource issues and water governance identified key results and lessons learnt from the case studies. This section gives an overview of the objectives, locations, methodology and structure of the case studies. The following sections present the specific results of the different case studies. Chapter 6 summarises the more general lessons learnt from the case studies for adaptation at a regional scale.

5.1.1 Focus and selection of case studies

The main objectives of this report are to gain some insights into the vulnerability of the European Alps to the impacts of climate change, focusing on water resources, and to assess possible needs, constraints and opportunities for adaptation to the adverse impacts of climate change on water resources. To gain a concrete understanding of the current and potential future water resource issues and adaptation options various regional case studies were conducted, which are presented in the following sections. The case studies focus upon regions that are already specifically exposed to these issues (shortages, quality) and in which adaptation activities have already been carried out — with the aim of learning about how best to address the issues of adaptation to water resource issues and future climate change.

The main questions addressed by the case studies are:

- What water resource issues have existed in the past in the regions and what problems should be expected from climate change in the future?
- Which adaptation activities to water resource issues have already been carried out in the regions?
- What activities are planned for future water resource issues, especially those due to climate change?
- What are the experiences and lessons learnt from these adaptation activities?
- Which barriers and drivers of adaptation can be identified?

The following criteria guided the selection of regional case studies on adaptation to water resource issues:

- existing or planned adaptation activities to water resource issues;
- interest expressed by the authorities in adaptation to water resource issues (not only, but primarily in the context of climate change);
- specific exposure of the region to water resource issues (shortages, quality);

- if available, historical climate records and results from regional climate models;

- if available, data records and scenarios on impacts of climate change;

- contact persons in the affected departments, sectors or groups.

Based on these criteria, the following case studies in different water-sensitive regions in the Alps were selected (see also Figure 5.1):

- River Lavant valley (Austria; see Section 5.2);

- Valais (Switzerland; see Section 5.3);

- South Tyrol (Italy; see Section 5.4);

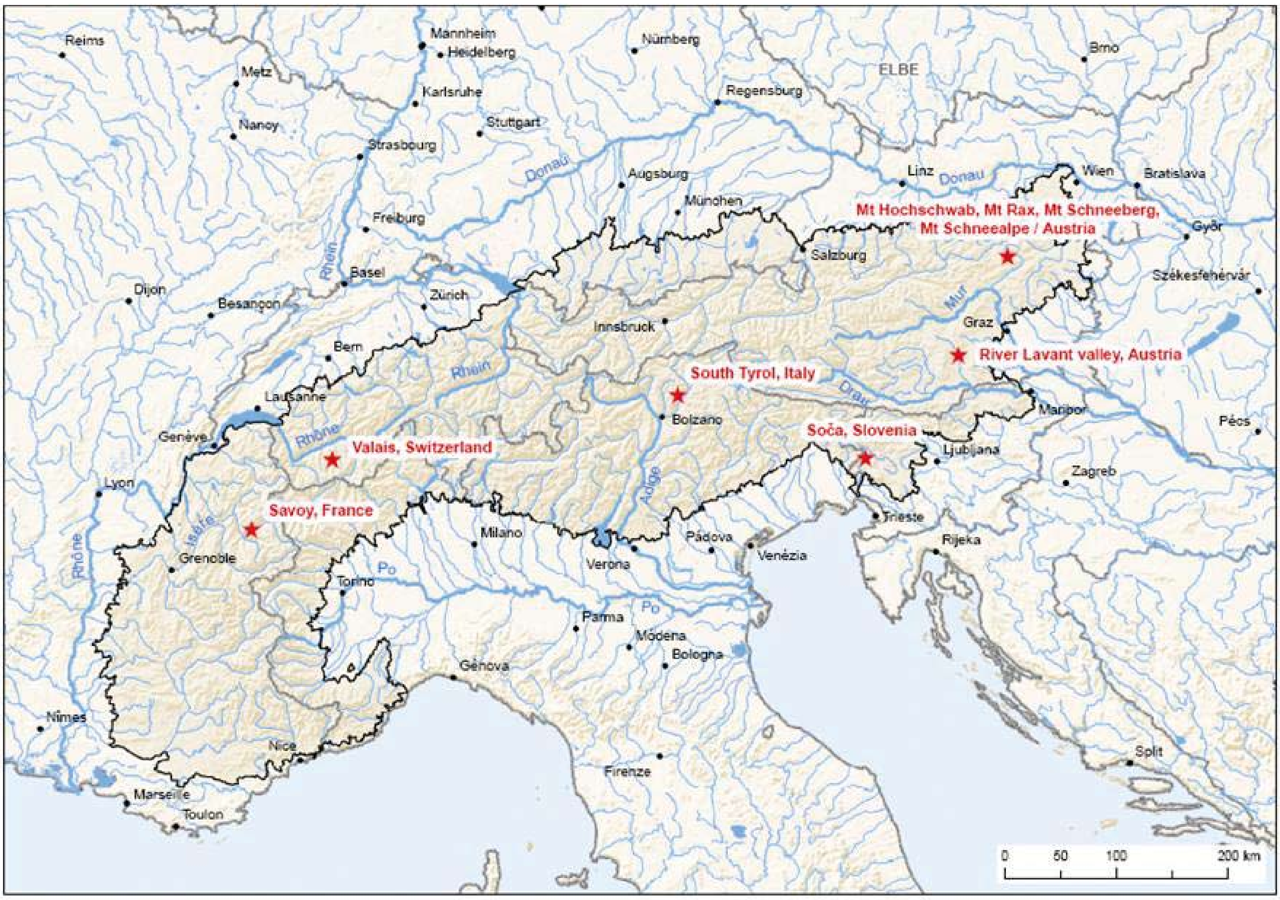
- Savoy (France; see Section 5.5);

- Mt Hochschwab, Mt Rax, Mt Schneeberg and Mt Schneealpe (Austria; see Section 5.6), shortened to Vienna's water mountains;

- Soča river basin (Slovenia and Italy; see Section 5.7).

The case studies on the River Lavant valley, Valais, South Tyrol and Savoy mainly address adaptation to water availability problems in the Alps, which include several municipalities. The River Lavant valley and Valais belong to Austria and Switzerland where water availability problems are generally seen as marginal. In Italy and France (including the case study regions South Tyrol and Savoy) there have been significant water-availability problems in the past. The case study on the four mountains that play an essential role for the drinking water supply of Vienna (Vienna's water mountains) mainly examines adaptation to challenges in terms of water

Figure 5.1 Case studies in water-sensitive regions of the Alps



Data source: DEM: GTOPO30 (U.S. Geological Survey, 1996); Perimeter Alpine Convention: SABE (Vers. 1.1) & Ruffini, Streifeneder, Elsen (2004), processed by Zebisch, EURAC (2006) based on EuroBoundaryMap (2004) and modified by Ifuplan (2007) and Umweltbundesamt (2007); Rivers & Lakes: CCM River and Catchment Database (European Commission - JRC, 2007); National Borders: GISCO Database (Eurostat, 1997 - 2000), Cities: ESRI basemap data

umweltbundesamt

Source: I. Roder, 2009.

quality. The Soča river basin study focuses on transboundary river management.

5.1.2 Methodology and structure of case studies

Data collection for the case studies combined a review of existing material on each case study region and interviews with stakeholders, decision-makers and experts. The review of existing material (especially from current research projects, but also from published literature, Internet sources, etc.) on the case study region focused on water resource issues, potential climate change impacts and adaptation to these problems in the regions. The partly standardised interviews (up to 15 interviews per case study) with people who were directly involved in the adaptation activities or had knowledge about them aimed at gaining a deeper and more detailed understanding of the water resource issues and the respective adaptation activities. The interview partners belong to government institutions, business organisations, non-governmental organisations or research institutions. The interviews focused on the adaptation activities and experiences, including economic, legal, and social barriers to and drivers of adaptation, and were based upon established interview procedures (Fowler and Mangione, 1990; Merton and Kendall, 1946/1979; Meuser and Nagel, 1991; Witzel, 1985 and 2000).

The data analysis and identification of lessons learnt followed an iterative approach:

1 The collected data were analysed and summarised by the case study authors.

2 Drafts of the written case study results were reviewed by the interview partners and revised accordingly by the authors.

3 A two-day workshop with experts on climate change impacts, water resource issues and water governance (23–24 October 2008, Bolzano, Italy) identified key results and lessons learnt from the case studies.

4 In order to identify the most important barriers and drivers of adaptation to water resource issues in the various regional case studies, the case study authors completed a questionnaire based upon the factors identified in the workshop, barriers and drivers of adaptation described in the 3rd and 4th Assessment Reports of the IPCC (Adger *et al.*, 2007; Smit and Pilifosova, 2001) and various publications on water management (including Falkenmark, 2007; GWP, 2000; Newig *et al.*, 2005; Ostrom, 2008; Pahl-Wostl, 2005).

5 In a final one-day workshop attended by most of the case study authors (5 December 2008; Vienna, Austria) the main lessons learnt and recommendations for adaptation to water resource issues and climate change were agreed upon.

This chapter presents the specific results of the different case studies. The adaptation activities on water resource issues in the region are described (for different sectors, in the past and planned for the future) and the experiences from adaptation activities, including adaptation barriers and drivers (political, socio-economic, technological, legal etc.) are presented. It also comprises details on the specific water resource issues in the region as well as other relevant information on the region (geographical location, population size, etc.). If available, data on past and future regional impacts of climate change on water resources are also presented. In the references at the end of this report, one can find sources and information on further material relevant to the case study regions and a description of literature and interviews upon which the studies are based. Chapter 6 summarises the more general lessons learnt from the case studies for adaptation at a regional scale.

5.2 Joint efforts against water shortages — River Lavant valley in Carinthia (Austria)

Summary

The River Lavant valley region (for its location, see Figure 5.1) is characterised by low precipitation, the limited number of springs that can be used for water supply and by its small pore volumes for storing water. The region has already been affected by water shortages during hot summers.

Although adaptation barriers such as the lack of responsive water management and long-term planning strategies on a regional and interregional level have hindered effective adaptation to these water resource issues, so far the region has been able to adapt to these problems. The following adaptation activities have proved particularly successful:

- establishment of an organisational arrangement for the supply of water, namely the water association network Lavant valley;
- management of the water demand through information for water users;
- awareness raising for water resource issues and individual initiatives for adaptation activities;
- participation in research projects to enhance awareness of climate change impacts and possible response strategies.

Due to climate change impacts, it can be expected that the water resource issues will increase and that further adaptation activities will be essential. So far, adaptations to the expected additional pressures are still under discussion in the River Lavant valley. If the area is to successfully adopt adaptation activities to deal with changing water resource issues due to climate change, the following will be required:

- explicit political will;
- binding legal framework;
- clear mandate for the establishment of interregional cooperation;
- cross-sectoral coordination of different water users and consistent implementation of water-saving measures.

In the case of forestry, successful adaptation can be assisted in the future by:

- increasing awareness of climate change issues among forest owners;
- enhancing financial incentives for forest owners to promote and encourage the introduction of locally adapted tree species in the lowland.

The following main lessons can be learnt from the case study:

- governmental activities in terms of providing strategic state-wide policies for water supply provide a trend-setting framework, but a clear mandate is necessary for effective adaptation;
- activities in terms of financial support enhance the success rate of measures taken;
- water supply networks connecting communities/regions can cope better with local water shortages. Although additional pressure through climate change on water resources might lead to uncoordinated reactions and individual solutions ('parochial politics', 'Kirchturmpolitik').

5.2.1 The region and its water resource issues

The River Lavant valley is situated at the southern rim of the main alpine ridge and is enclosed by the Saualpe in the west and the Koralm in the east, both are mountains with altitudes ranging between 2 000 and 2 100 m. The springs in these two mountain ranges provide most of the water for the municipalities of the Lavant valley. The region has already been affected by water shortages during hot summers.

Wolfsberg, the district capital, and St Andrä are the largest towns in the region. Both municipalities are composed of a large number of dispersed communities, but most settlements are located at the bottom of the valleys along the River Lavant and its tributaries. Wolfsberg, approximately 460 m above sea level, covers 278.31 km² and has 25 438 inhabitants (2005). Large parts of the municipal area (49 %) are covered by forest; other areas are under agricultural use (29.3 %) or consist of alpine land (14.9 %). The employment rate of the primary sectors (agriculture, forestry, mining and quarrying industries) is approximately 6 % in Wolfsberg and 10 % in St Andrä. St Andrä, approximately 430 m above sea level, covers 113.46 km² and has 10 647 inhabitants (2005). Half the municipal area is under agricultural use and 40 % of the area is covered by forests (Statistic Austria, 2007a and 2007b).

Effects of climate change are already noticeable in the River Lavant valley. In the River Lavant valley, the average annual temperature has increased from 7.2 °C to 8.4 °C from 1961 to 2006, which equates to a trend of warming over the same period of 1.2 °C (ZAMG, 2007). The increase in average annual temperatures in the period 1961–2006 was greatest in summer (+ 2 °C), followed by winter (+ 1.4 °C), spring (+ 1.2 °C) and autumn (+ 0.7 °C). The average annual precipitation in the region is between 750 and 950 mm at low altitudes and up to 1 300 mm at the highest altitudes. In the observation period 1900–2001, annual precipitation in the River Lavant valley decreased by approximately 15–25 % (Moser, 2007; Moser *et al.*, 2002). The decrease in seasonal precipitation in the River Lavant valley region was greatest in winter, when it amounted to more than – 35 %. The smallest decreases were observed in spring and autumn. In summer, a noticeable decrease of – 8.5 % was recorded.

Future scenario ([20]) simulations (REMO A1B; see Chapter 2) for the River Lavant valley indicate an annual temperature increase of more than 1 °C up to the year 2030. Up to 2100, warming is projected to continue linearly, with an annual average temperature increase to a total of approximately + 4.5 °C by the end of the 21st century. In contrast to temperature projections it is important to consider that climate model-based scenarios of future trends in precipitation are generally characterised by considerably larger uncertainties and much broader ranges in variation. The REMO A1B scenario shows significant increases in precipitation in winter and in spring for the case study region in the long term, which exceed current precipitation amounts (1961–1990) by 10 %. By 2050, summer precipitation starts to decline significantly until average seasonal amounts of precipitation are almost – 15 % below the levels of the climate reference period. In general, the results of these future climate scenarios are more difficult to interpret in terms of their implications for groundwater stocks and groundwater renewal. One reason is that neither temperature increase nor precipitation regimes are correlated in a linear way with quantitative and qualitative aspects of the groundwater situation. Nevertheless, it can be expected that changes in precipitation patterns will lead to greater variability in groundwater levels and in discharges of springs and wells. Combined with higher withdrawal rates during dry and hot summer periods, bottlenecks in water supply could become more frequent than today.

In the case of precipitation events (number of days with precipitation), the REMO A1B scenario indicates an increase in the winter season. In summer, it is very likely that heavy precipitation events will become both more frequent and more intense, especially linked to more intense thunderstorm activity. Intense precipitation events imply that, depending on the pre-moisture status of the soil, less water is able to infiltrate into deeper soil layers, geological layers and groundwater bodies, and more water flows directly into surface water bodies via surface run-off. Apart from causing increased risk of flooding, this may adversely affect groundwater renewal rates, water availability for vegetation, and water supply for municipalities.

([20]) Projections of future climatic development are based on a certain choice of climate models, emission scenarios and corresponding model runs, which determine to a considerable extent the quantitative magnitude of projected long-term changes in future climate. While uncertainties caused by climate models and their underlying assumptions can to some extent be reduced, the different emission scenarios reflect the basic uncertainty about global future paths of development and corresponding greenhouse gas emission levels; this source of uncertainty is inherent to future projections and cannot be reduced to a large extent. In the model region, mainly the 'intermediate' SRES (Special Report on Emissions Scenarios) emission scenario A1B has been chosen to develop a regional climate scenario for the River Lavant valley, which is based on fairly optimistic assumptions and would result in comparatively moderate global climate change (Lexer *et al.*, 2007).

5.2.2 Adaptation activities and experiences

Adaptation activities targeted at low water availability have already been required in the River Lavant valley. The main activities are to secure water resources for the public water supply. Further measures have been put in place for forestry, which has already been negatively affected by climate change impacts (see Figure 5.2).

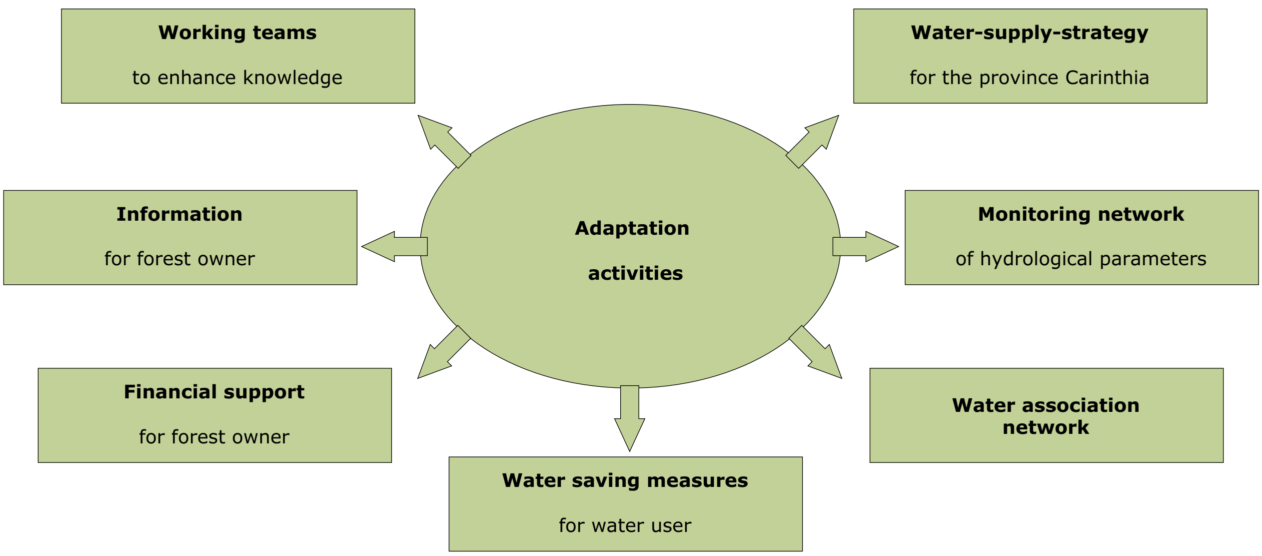
Water supply
Since 1984, governmental agencies in Carinthia have been working on a state-wide water-supply strategy (Wasserversorgungskonzept Kärnten), presenting data on water availability and water demand at a regional scale. Based on this information, suggestions for a sustainable water supply were prepared for communities. One of the priority objectives is to connect the water supply networks of the municipalities. Furthermore, a monitoring network with 200 stations has been set up to show the actual trends in hydrological parameters like groundwater stock or run-off patterns.

As early as 1994 the water association network Lavant valley (Wasserverband Verbundschiene Lavanttal) was established as a response measure to recurring water supply shortages in the region. The Lavant valley region is renowned for its lack of precipitation; however, precipitation is the most important source for groundwater recharge. In addition, the geological bedrock is composed mainly of crystalline rocks, which have only small pore volumes for storing water. Therefore, the water storage capacities as well as the deliveries of springs are rather low.

The foundation of the water association network Lavant valley evolved from the initiative of one person, who was aware of the local situation regarding water supply difficulties. This person was a renowned water expert with good connections to relevant decision-makers at governmental and political level. At first, the network was controversial and opposed by a large part of the local population for economic reasons. But water shortages in recent years underlined the importance of the project and helped increase its acceptance.

Since 1994, the water association network Lavant valley has developed new water resources and connected the water supply networks of the municipalities Wolfsberg, St Andrä, St Paul and St Georgen in order to cope with temporary local water shortages. Today, the water association network owns a conveying system that can provide an annual discharge flow of 260 000 m³. The water comes from 12 springs on privately owned land; water withdrawal is secured by the water association network through long-term contracts. This strategy of risk management has proved successful for approximately 42 000 consumers connected to the public water supply system.

Figure 5.2 Adaptation to water resource issues in the River Lavant valley



Source: ETC/ACC, 2009.

Photo: © European Environment Agency

Many problems related to climate change impacts can be reinforced by certain modes of human behaviour. Apart from a larger variability of water stocks caused by climatic impacts, the consumption of water resources also has an influence on the vulnerability of water supply within the region. Usually, and in particular during dry and hot periods in summer, reduced availability of water resources coincides with an increase in water demand by citizens, tourism and agriculture, which in the past has caused temporary bottlenecks for water supply in the region. In response, the municipalities of the Lavant valley provide information about water-saving measures for their customers. In summer 2003, which was characterised by extremely hot temperatures and little precipitation, households were particularly requested to save water by stopping activities like watering the grass or washing the car. Water-saving measures aimed at reducing consumption of the resource water have greater potential to safeguard the security of water supply than actions that attempt to influence the availability of water resources themselves. Promoting initiatives to use water more economically is certainly a suitable adaptation measure that has a great potential, since reducing water consumption is able to effectively counteract climate-induced (temporary) water shortages. Increasing in the future the level of information and awareness-raising activities aiming at reducing water consumption, would significantly contribute to ensuring sufficient water supply in the region.

The vulnerability of water supply in the two municipalities Wolfsberg and St Andrä is different for households that are hooked up to the public water supply network when compared to that for households that rely on private wells. Supply problems for those households not connected to the public supply network have occurred several times in recent years and remain quite likely to occur in the future, as stronger fluctuations in groundwater levels and discharges of wells are to be expected. The vulnerability of this individual kind of water supply thus has to be considered as high (ClimChAlp, 2008). The connection of the water supply networks of the municipalities in the region by means of the water association network Lavant valley reduces the water supply sector's vulnerability, which is considered to be medium in future for both model municipalities: Wolfsberg and St Andrä (ClimChAlp, 2008). Nevertheless, the extremely hot and dry summer of 2003 showed clearly that there is only a limited amount of water available, which does not adequately fulfil the needs of the communities. So far, the water association network can provide around 15 l/s water, but bearing in mind the additional pressure of climate change effects, more than double this amount would be necessary to secure a sufficient water supply for the region in dry periods. The water association network — together with the municipalities — is now seeking new alternatives to improve the security of the water supply in the River Lavant valley. Unfortunately, the development of new spring water sources in the Saualpe and Koralm mountain ranges is unlikely as nearly all known springs have been welled and connected to the public supply network. One option currently being considered is the inter-regional extension of the water association network — connecting the water supply network of more regions with different climatic characteristics could lead to greater security of supply during risk periods. Another option under discussion is the use of deep groundwater from the valley. In the course of drilling for thermal water, experts expect to find a groundwater body at 200–300 m depth. Nevertheless, the use of deep groundwater is constrained by two factors: it is expensive and in general questionable from an ecological point of view.

Forestry

In the River Lavant valley, adaptation of forestry to climate change is of particular importance. Forests cover 40–50 % of the total area and the sector has a significant role locally in Wolfsberg and St. Andrä as well as on a national scale. 73 % of the total forest land is owned by small family farms. Norway spruce, which has been extensively introduced in lowlands below 900 m in the past, is at 72 % clearly the dominant tree species in the region. Since spruces prefer cool and wet sites, they have already reached the limits of their tolerance under current climatic conditions in the lowlands of the River Lavant valley. Moreover, their flat root systems mean that spruce stands are particularly susceptible to wind damage. The heavy storm 'Paula' in January 2008 destroyed around 500 ha of forest in the River Lavant valley region. Weakened forest stands are much more likely to succumb to pests such as the bark beetle, which also profits from the warming climate. In the Lavanttal, forests have been affected by lack of water and by increasingly frequent infestation of bark beetle. Further stress could lead to ecological destabilisation of forest ecosystems and could threaten the fulfilment of their protective functions in terms of the ecosystem services they provide. In particular, reduction of the water storage and retention capacity of forests could accelerate and increase the build up of floods.

Spruce trees were artificially introduced into the lowlands — outside their native range — in the last decades, mainly because they are fast growing and a particularly good source of timber. However, the changing climate has caused deterioration in the health of the trees, adversely affecting productivity and income. The Wolfsberg district forest authority ('Bezirksforstinspektion Wolfsberg') has established a working team on mixed-forest stand management, which is collaborating with experts from other countries like Germany. The aim of the working group is gathering vital information on the management of mixed forest stands (which are more adaptable due to genetic diversity), in order provide a solid consulting service for forest owners. To overcome reluctance to change, a financial support programme has been set up to promote and encourage the introduction of locally adapted tree species in the lowlands.

The future vulnerability of forestry in the Lavant valley is judged to be high in the medium term, especially in forest stands dominated by spruce trees (ClimChAlp, 2008). If the tree species composition is changed, long-term vulnerability could be reduced (since mixed stands are generally less vulnerable than monocultures). But because the production cycles are so long within this sector, adaptation measures require proactive planning. Changing the species composition, could take several decades.

5.3 The Valais — an inner-alpine valley traditionally adapted to arid climate (Switzerland)

Summary

As an inner-alpine arid valley, the Valais has always been required to adapt to temporal low water availability (for its location, see Figure 5.1). In the past, water resource issues in the Valais occurred only locally and temporarily, as interviews with stakeholders from different sectors have shown. Traditionally, water needed in summer is taken from groundwater or glacial melt run-off, water in winter is taken from reservoirs. Water-related conflicts of interest have been rare. In the future, due to climate change, water resource issues will increase because there will be less glacial melt water to compensate for summer drought, with effects on groundwater capacity. Stakeholders expect that conflicts that can be solved today at local level might have to be resolved at regional level in the future.

Adaptation measures in the past:

- past measures have been mainly technological measures, reacting to existing pressures and implemented on a local, municipal scale;
- the water supply system is a matter for each municipality and therefore there seems to be no need for regional collaboration, except in the hydropower sector. Up to now, interregional coordination has not been necessary, since the Valais is hydrological well confined;
- most measures are primarily motivated by economic reasons or by the task to reduce risks of natural hazards. Also measures with negative side effects in regard to climate change (gas heating for frost protection, artificial snow production) are used.

Adaptation measures to decreasing and changing availability of water resources due to expected climate change are still lacking. However, some interviews have shown that there are such plans and first approaches, especially in the hydropower and forestry sectors. Adapted forest management is under way and different tree species are being planted. Many small power plants are planned along running waters, including drinking water pipelines, bringing potential for conflict with ecosystem protection. In the household and agriculture sectors further water saving potentials exist. In some sectors and regions adaptation is very difficult: experts' views are that some of the current land use cannot cope with higher temperatures and longer droughts (native forests below 1 000 m) or without glacial melt water in the summer (pasture farming at medium altitude).

The following main lessons can be learnt from the case study:

- accepted traditions, rules and laws, the distribution of responsibilities and existing communication networks, which do not need to be formally institutionalised, help to decrease conflicts between stakeholders;
- public awareness of the need for adaptation to climate change is low because so far there has been no drastic experience of water scarcity;
- political will and mandate are needed for a coordinated approach to adaptation to climate change;
- measures are accepted and successful when also driven by other interests and when economically beneficial;
- long-term adaptation planning occurs mainly in sectors requiring long-term investment (hydropower, forestry). In other sectors planning and actions generally relate to the shorter term;
- there is a general feeling that in order to put in place concrete adaptation actions, more detailed knowledge about the future local impact of climate change on water availability is required.

5.3.1 The region and its water resource issues

Geography

The canton of Valais is situated in southern Switzerland. It numbers 291 575 inhabitants (2005), living in 153 municipalities (2000) (Staat Wallis, 2005). With a population density of 55.8 inhabitants per square kilometre the region is rather sparsely populated (BfS, 2008). Due to river correction in the 19th century, the Valais gained large areas of fertile soil on the valley floor, which today is predominantly used for cultivation of vines, fruit and vegetables in the Middle Valais and tillage in the Lower Valais. The valley floor of the Upper Valais and the mountain sides are used for extensive dairy and pasture farming (BfT, 2004). Chemical and heavy industries settled here at the beginning of the 20th century, mainly because of available water power. Mass tourism is concentrated on several destinations such as Zermatt or Leukerbad (Schumacher, 1999). In 2001, 11 % of employees worked in the primary, 26 % in the secondary and 63 % in the tertiary sectors (BfS, 2008): of those working in the tertiary sector 43 % worked in tourism (Berwert *et al.*, 2002).

The Valais covers nearly the entire basin of the Upper Rhone. It is enclosed by high mountain ranges and is an inner-alpine arid valley. The Rhone, as the lifeline of the region, has its source in the high alpine conditions of the Rhone glacier at 2 274 AMSL (above mean sea level) and drains the major part of the Valais. It flows into Lake Léman (372 AMSL) after passing through 170 km of different vegetation zones. Forests of pines and oaks grow in Central Valais, and the so-called rock-steppe, with Mediterranean vegetation species, is situated on its south-facing slopes (Schumacher, 1999). The landscape at medium altitude is characterised by expansive mountain forests, with pastures both above and below. More than half of the Valais consists of rocky landscapes with ice at the highest elevations over 4 000 AMSL. Of the total area (5 225 km^2), 22.8 % is overgrown with forest and woodlands; only 20.3 % can be used for agriculture (BfS, 2008).

Water resources and climate change

According to the experts interviewed, as yet there are no known water quality problems and no general problem with water availability in the Valais, because of existing water buffers (glacier, snow, and groundwater), comprehensive experience with (summer) droughts and a long tradition of irrigation in agriculture. Water-related conflicts of interest are very rare. However, there have been local and temporal water shortages. The complex topography of the Valais is responsible for a divergent precipitation pattern (Volken, 2008). Precipitation ranges from 500 to 900 mm per year in the inner-alpine valley between Martigny and Brig to more than 3 500 mm per year on the highest peaks in the northern and north-western part of Valais (BfT, 2004). Evaporation varies from below 100 mm per year in north facing high-peak regions to around 1 000 mm per year on slope sites in the Upper Valais (Goms) and in the Lower Valais below Martigny (BfT, 2004). There are some arid regions during all seasons, mainly on the valley floor where potential evaporation is greater than precipitation, which is compensated by groundwater as well as run-off from snow and glacial melt (BfT, 2004). Between 1970 and 2007, the mean temperature has risen in Switzerland by around 1.5 °C (Frei *et al.* 2008). The glaciers have melted drastically, e.g. the glacier Aletsch shortened by 838 m (1974–2003, BfT, 2004). At present, the increased glacial melt raises summer run-off by 1.2 % per year (Frei *et al.*, 2007). The Rhone run-off regime at Brig is glacial with peaks in the summer and minimum flow in winter.

Looking into the future, rising temperatures, similar to those already experienced in the 1990s, will change the alpine environment (Beniston, 2004). In southern Switzerland, temperatures are expected to rise over a 1990 baseline by 1.8 °C in winter and 2.8 °C in summer by 2050 (Frei *et al.*, 2007). Generally, global warming leads to a northward and upward progression of climatic zones. According to Beniston (2004) the Valais' temperature and precipitation characteristics in future may therefore resemble a type of climate that is currently found in the Mediterranean Alps of southern France. This would imply a tendency towards wet winters and long, dry and warm summers. In fact, the precipitation scenario of Frei *et al.* (2007) shows a decrease in summer of about 19 % and an increase in winter of about 11 % in southern Switzerland up to 2050. Also, more frequent extreme events (droughts, heavy precipitation) are expected. Heavy precipitation might trigger natural hazards (floods, landslides, mudflows, soil erosion). Furthermore, simple estimations based on these climate change scenarios result in a decrease in glacier area of between 50 and 90 % by 2050 compared to the reference period (1971–1990). Small glaciers that are not located at high altitudes may disappear. According to Frei *et al.* (2007) regeneration of groundwater will decline in all glacier-free areas in summer and autumn and average evaporation will increase in summer. As a consequence of the changing accumulation and melting of snow cover, the receding snow limit and the increased glacier melt, as well as more heavy rain in winter, the run-off regime will change. Summer run-offs will be lower with streams drying out and winter run-offs higher with an increasing danger of floods.

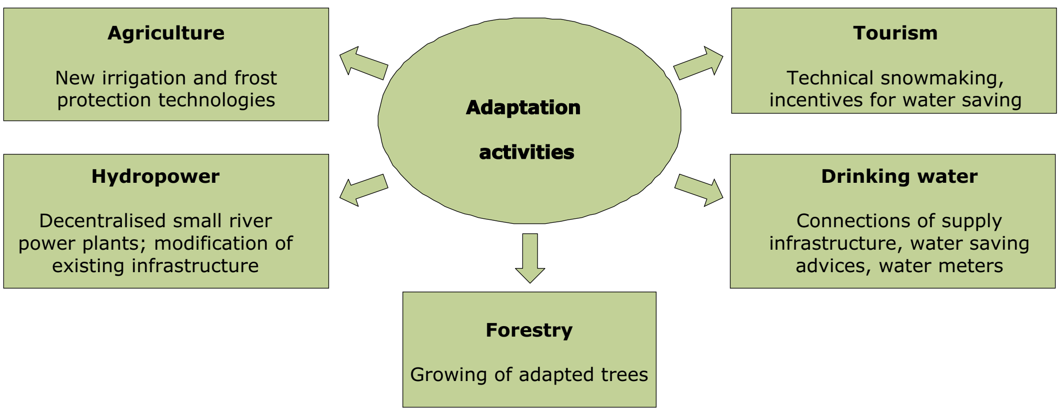
5.3.2 Adaptation activities and experiences

The Valais is traditionally adapted to low water availability. Today, further local measures are used in all sectors, which lead to decreasing water consumption or better exploitation of the water resources.

Drinking water is mainly extracted from groundwater and slope springs which are partly fed by snow and glacial melt water. Hydrologists and water users expect negative effects on the groundwater of future reductions in melt water. In the past, there was a lack of water locally in springs at valley locations when drinking water was used to irrigate gardens before the snow melt in the mountains. To prevent water scarcity, some municipalities have linked their local water supply infrastructures, although only surplus water is given to other municipalities. Furthermore, regulations have been partly implemented to save drinking water in the spring, including recommendations to not use water for gardening. Water users judged these to be acceptable because the problem was created by wasting water. Moreover, water meters are increasingly being installed to take advantage of demand-dependent pricing. Water pipelines to supply villages and cities in other regions ('Valais as water tower') have been discussed, but have not been realised so far.

Despite an adapted agriculture in the Valais, experts stated that in some areas more water (approximately 800 mm) is needed than is provided by precipitation (400 to 600 mm in the Middle Valais). Additional water is needed for irrigation, which is taken in summer from groundwater on the valley floor as well as from snow and glacial melt water on the slopes. This water is traditionally collected at the glacier mouth and led by 'Suonen', (canals), to the fields. Agricultural experts expect that rising evaporation and decreasing buffer capacities, in addition to changing pattern of precipitation and longer periods of drought, will lead to serious problems in 20–30 years. Future conflicts of interest with tourism and hydropower are seen as possible. The experts reported that in the past few years, new technologies have been implemented in fruit and wine production to save money and water (for example, drop irrigation, frost protection by gas heating instead of water spraying, development of new models for estimation of the optimal quantity and time for irrigation). In the meadows covering the slopes, new sprinkling irrigation technologies are used to save working time and water. Further, the traditional Suonen system for capturing glacial melt water and transferring it to cultivated slopes is being restored, with synergistic effects for tourism and fire control. Agricultural experts pointed out that most measures have been undertaken by single stakeholders or by communities acting on their own account, except for the restoration of the Suonen system which has been undertaken and financed by the cantonal and national administration in the framework of structural subsidy. The measures, which were motivated by economic considerations, saved water, thus providing synergistic effects, which led to their high acceptance. Agricultural experts judged that at the community levels there have been no conflicts between stakeholders and sectors so far, because rights, competences and responsibilities

Figure 5.3 Adaptation to water resource issues in the Valais



Source: ETC/ACC, 2009.

Photo: © Canton Valais (François Perraudin)

are clearly defined. The ongoing expansion processes on the slope sites are driven by economic factors and agricultural policy rather than by water problems. They also estimated that there is still a large potential for saving water (for example by technologies, agricultural crops, production methods).

Forestry experts judged that the natural vegetation in the Valais is well adapted to water scarcity. If a dry summer is followed by cold, wet summers, the vegetation can recover. However, increasing temperature and declining water availability affect Scots pine more than Pubescent oak. Due to increasing aridity in summer, Scots pine are already declining on slopes below 1 000 m and being substituted by Pubescent oak, with similar ecosystem benefits. The experts expect that this process will continue and intensify in future and that in areas below 1 000 m it will lead to conditions under which native tree species cannot persist. Additionally, the danger of forest fires will be enhanced. To meet these trends, adapted management strategies are being developed: on the one hand, Scots pines are rejuvenated at places with good conditions, on the other hand adapted trees (e.g. Pubescent oak) are planted occasionally to minimise the risks of complete destruction of the forest and thus to ensure the provision of ecosystem services (e.g. protective function). So far only native species have been planted. A fire control policy has been created on a cantonal scale for preventive planning and organisation to combat emergencies (firefighting management, mapping, forestry measures such as tree mixtures, forest aisles etc., reservoirs and pipelines for firewater).

As for hydropower, the major impacts of climate change are thought to be the increasing amount of suspended loads as well as the release of debris material in areas where glaciers are retreating. This is expected to cause an increase in maintenance as well as huge investments for modifying the water catchments. Moreover, operators judge that the changing water supply (more frequent and heavier precipitation in winter, less glacial melt water and precipitation in summer) implies a decrease in water scarcity in winter, from which hydropower will benefit, and an increase in water scarcity in summer, from which hydropower generation will suffer.

According to operators, an increase in future electricity production could be achieved by increasing storage capacity or by increasing the number of hydropower plants, which would have potential negative effect on the residual flow. However, further exploitation of water resources is limited because, since 1991, hydropower companies have been obliged by national legislation to protect the landscape and water (residual flow ([21])). Installations built before 1991 can still reduce the flow below the ecological minimum until their concession has to be renewed, which creates conflicts with ecosystem protection. Hydroelectric pump storage will continue to enable the reuse of water for producing peak energy according to increasing demands. New decentralised river power plants have been planned or partially constructed along creeks, small rivers, and drinking water pipelines for economic reasons, to protect local companies from global energy prices and to use the potential of hydropower more effectively. This creates potential for conflict with local stakeholders with regard to the protection of the remaining free flowing creeks. Measures to increase reservoir volumes in order to balance seasonal water availability and to protect against floods are being considered by hydropower operators and regional authorities. However, scientists judge that the hydropower capacity of the Valais is nearly exhausted. Due to the long running time of water concessions (several decades), long-term planning is a crucial prerequisite for hydropower stations. Some hydropower operators expect future conflicts concerning interests of different stakeholders, especially with environmental organisations. Stakeholders already emphasised the need for regional and cross-sectoral coordination during the planning process. Water used for hydropower

([21]) Since the Federal law on water protection (Bundesgesetz vom 24. Januar 1991) was put into force it is mandatory to leave adequate residual flows in watercourses. This clause only comes entirely into effect in the case of new extraction or of renewal of concessions (BWG, 2001).

is not lost but can be used afterwards for other purposes. Water required by municipalities or tourism organisations is delivered on demand (not to drinking water quality); the quantity of water used in winter tourism for artificial snow-making is relatively small up to now.

Tourism destinations face negative impacts as a result of natural hazards, the retreat of glaciers and lack of snow: for example melting permafrost will affect some winter tourism destinations. Tourism managers stated that, whilst artificial snow-making is a very important adaptation strategy to climate change, it is locally limited due to water shortage. Reservoirs are being constructed to improve water availability for artificial snow-making. Furthermore, incentives for water saving include the awarding of optional labels to tourism enterprises. For example, the award of the 'Valais excellence' label is connected to implementation of environmental obligations.

Tourism managers judge that there are no conflicts in the region concerning water resources which cannot be solved among local stakeholders (e.g. presidents of municipalities, farmers). Within the municipal water supply, the top priority is meeting the demand for drinking water and artificial snow-making is stopped if water is scarce.

Different stakeholders reported that municipalities implemented multiple water use systems, for instance where small hydropower plants are installed along drinking water pipelines, unused irrigation water is pumped into reservoirs and the stored water also serves as water for firefighting, or water used for snow production is collected after snowmelt and used to generate hydropower. Moreover, the planned third Rhone correction serves not only for flood protection, but is supposed to balance water demands from agriculture and tourism, as well as ecosystem services.

5.4 A long history of adaptation — water availability in South Tyrol (Italy)

Summary

Parts of South Tyrol (Vinschgau and the dry plateaus around Bolzano and Brixen) belong to the dry inner-alpine valleys, where water has been a rare resource for centuries. In response to this problem, South Tyrol (for its location, see Figure 5.1) has a long history of adaptation to water scarcity with a traditional and complex system of irrigation channels, water rights and local water managers.

In the last decade, mainly due to a series of dry years combined with an increasing demand of water for irrigated agriculture, tourism and household, water scarcity has become a challenge in particular seasons (early spring, high summer) in parts of South Tyrol. While the total amount of water available within the region is enough, water scarcity arises from an uneven temporal and spatial distribution of demand and supply.

To what degree a sector or system is susceptible to water scarcity depends on various local factors. For instance, dry regions are more affected than humid regions and surface water dependent water use is more affected than ground water dependent water use. Climate change scenarios for the region project a decrease of precipitation, particular in summer, which would increase the pressure on sensitive regions and sectors.

Adaptation measures in the past

The ongoing adaptation measures in South Tyrol mainly focus on technical solutions (e.g. improved irrigation technologies, improved artificial snow-making methods, and reservoirs) and on inter-sectoral water management by means of a common water use plan and a related system of water concessions. A system of regulation and financial subsidies supports the introduction of innovative, water saving techniques. Barriers to adaptation are inter-sectoral communication on water scarcity, which is not well established, and a relatively rigid system of concessions based on traditional water rights.

Adaptation measures that respond to a reduction in water resources and changes in water resource availability due to climate change are still lacking. Awareness of climate change is growing but until now climate change is not considered explicitly in any management plan for any sector. There is, however, an enormous potential for savings in water consumption (above all in agriculture, private households and in the tourism sector), which allows for further adaptation in this area.

The following main lessons can be learnt from the case study:

- growing water demand is a bigger challenge than decreasing water availability.
- extreme events in the past (e.g. the summer drought of 2003) have triggered adaptation measures.
- inter-sectoral harmonisation works well, where properly supported by a sound legal framework (water management plan).
- a traditional system of water rights can be a barrier for adaptation, if it is too rigid.

5.4.1 The region and its water resource issues

The Province of Bolzano, also known as South Tyrol, is the northernmost province of Italy, with borders with Austria in the north and east, and Switzerland in the west. The province has an area of 7 400 km² and a total population of 487 673 (2006). The region is renowned for its mountains, such as the Dolomites, which make up a significant section of the Alps. Altitude above sea level ranges from 200 m in the southern Adige Valley to 3 905 m in the Ortler region, with 86 % of the total area being located above 1 000 m.

South Tyrol shows a typical horizontal structure, with densely populated and intensively used valley bottoms (vineyards and fruit orchards in the south and west, intensively farmed grassland in the north and east), plateaus on lower mountain ranges (between 1 000 m and 1 600 m), which are dominated by intensively farmed grasslands and forest, a forest belt (between 1 400 m to almost 2 000 m) and an alpine zone with pastures, dwarf shrubs, natural grasslands, rocks and glaciers.

Climate varies with altitude, from a temperate, humid climate in the valleys, through a boreal climate in the forest belt to a polar/alpine climate above 2 000 m. Climate may also vary with geographical region.

The Vinschgau, in the west, is one of the inner alpine dry valleys, with less than 500 mm precipitation per year at the valley bottom. While in the Pustertal, in the north-east, precipitation reaches values of 1 200 mm per year in the valley and more than 2 000 mm per year in the mountains.

Hydrologically, South Tyrol covers the headwater catchment of the Adige almost completely. This is the second longest river in Italy, which makes the region an important water source for the downstream region in Veneto with its intensively irrigated agriculture. Snow and glaciers play an important role in the hydrological cycle of the region and act as natural water storage.

In South Tyrol, many sectors rely heavily on water. Agriculture is the largest user followed by industry, households and tourism (artificial snow-making). Hydropower plays an important role, since more the 90 % of the energy is hydro generated. Water consumption for all sectors is regulated through a water use plan and a system of water taxes, which vary from sector to sector.

The dry regions of South Tyrol in particular show a long history of adapting to low water availability, including a traditional system of irrigation channels (Waale) and water rights.

While a slight trend of decreasing water availability has been recorded over the last few decades, the consumption of water in all sectors has risen significantly.

Even if water scarcity is not a general problem in South Tyrol, developments in the last decade, with rising water demand in all affected sectors and six relatively dry years in sequence (2001–2007), have shown that water is a rare and valuable resource in the region. In line with the alpine-wide results (see Chapter 2), climate scenarios for the region project a shift in precipitation from summer to spring and late winter, with a decrease in precipitation in summer of between 5 and 15 % until the middle of this century, and decreasing further, by almost 40 %, by the end of the century.

5.4.2 Adaptation activities and experiences

Agriculture

Status quo and trends — Agriculture (grassland, fruit horticulture, viticulture etc.) is the largest consumer of water in South Tyrol. More than 70 % of total water consumption is used for irrigation. There has been a continuous increase in water consumption over the last few decades, which is mainly due to an expansion in the area of agricultural land requiring irrigation. In the district of Vinschgau, for example, an expansion of agricultural land-use (fruit-growing areas) by up to 20 % is expected (stakeholder estimate). On the other hand, there is a high potential for water savings within agriculture of up to 40 % (stakeholder estimate) by introducing modern irrigation techniques.

Agricultural water requirements are highest in early spring due to sprinkler freezing (which protects blossoms from frost), at a time of the year when less water is available in the rivers, as the snow melt has not yet set in. Declining water availability (which is already noticeable in agriculture) is seen as less problematic than a general increase in the demand for water from other sectors such as hydropower, households and tourism.

Adaptation potential — In the past adaptation had mainly been achieved through more efficient irrigation methods, for instance by introducing the technique of extensive drip irrigation for fruit-growing (which can save up to two-thirds on the quantity of water used). In addition, there has been investment in deep wells as well as reservoirs, in order to adapt to lack of water in peak times of water demand. The situation is different for irrigated grasslands; since here the technical as well as the financial potential for water saving irrigation is very limited.

For the future, it may be deemed necessary to tap into the potential for savings using further adaptation measures, such as the conversion to more efficient irrigation methods (e.g. extensive drip and underground irrigation etc.). Drip irrigation should be a legal requirement, which is presently only the case for newly awarded water concessions. There are potentials for further optimisation by adopting technical measures such as determining the level of soil moisture. A potential lowering of groundwater in peak seasons due to an increase in water demand (early spring, summer) would raise the demand of deep wells in the future. The construction of reservoirs (for sprinkler freezing, but also for irrigation in the summer) is also seen as important, in particular to adapt to the projected overall decrease in summer precipitation but with an increase in heavy rain fall which is of no use for agriculture at present.

Drivers and barriers — One of the drivers of adaptation in South Tyrol in the past has been the high technological level in irrigation techniques (such as drip irrigation) and in water management (reservoirs) as well as the financial and logistical support by the province in introducing such innovative techniques. The same is true for the possible provision of new water concessions with restrictions (for example, with the obligation to use drip irrigation). The 'Water Utilisation Plan' is a further example of success, because it is legally sanctioned and has a cross-sectoral foundation. A reinforcement of awareness-raising amongst the population, as well as in the agricultural sector, concerning the theme of water use/water consumption is also an example of a driver.

The fixed character of the current concession system was identified as a potential constraint. Since this system is based on traditional water rights, it can hardly be adjusted to future needs to reduce water consumption. In addition, there is also a lack of the sense that climate change will/could have a negative effect on water availability in South Tyrol. A further barrier to adaptation is water conflicts between farmers who compete for the same surface water. Among other technical barriers is, the fact that that there is no adequate alternative to the water demanding technique of sprinkler freezing.

Photo: © Marc Zebisch

Cost-benefit considerations hinder adaptation measures in the area of grassland irrigation ('it is simply too expensive').

Drinking water

Status quo and trends — In general, drinking water supply in South Tyrol is not a problem. Anyhow, there is a distinction between spring water and ground water based supply. Most of the urbanised municipalities in the valley extract their drinking water from ground water which has shown a fairly constant ground water level in the last 30 years, apart from slight variations. In contrast nearly all rural municipalities take their drinking water from springs, where the temporal and spatial distribution of water availability might represent a challenge in dry periods (such as spring, dry winter or hot summer). This problem is increased by faulty pipes (water losses of 30–50 %). The main reason for this is the large, branched pipe network. In the district of Vinschgau there is the further problem of water quality (salinisation).

Adaptation — Due to the present recorded loss of 30–50 % from drinking water pipes, no new drinking water concessions will be awarded without the presentation of 'proof of water pipe loss'. In addition, there is the grouping together of communes within the framework of an integrated system (e.g. Passeiertal). A further adaptation measure is the ongoing construction of deep wells in order to work against the slight drop in groundwater level. Furthermore, the population is motivated by a range of PR campaigns aimed at saving water.

In the future increased monitoring of water availability will be carried out in order to be able to respond early to a reduction in availability. A potential future adaptation measure is the construction of drinking water pipes into dry zones; however, construction costs for laying the pipes and energy costs for the pump need to be taken into consideration.

Drivers and barriers — A driver can be seen in legal regulations within the framework of a new concession award system, for example, the mandatory proof of water pipe loss. The present, well established monitoring system, as well as the water utilisation plan can be regarded as additional drivers.

A major constraint in the area of drinking water is the lack of communication and collaboration between the different stakeholders, above all between communes. The lack of collaboration within the framework of water distribution at the commune level can be partly explained by regional spread (zones that are too far apart), and partly by lack of political will. Regarding the defective drink water pipes it should be noted that, because of the low drinking water price, the commune has no income to repair its damaged pipes, and/or construct deeper wells and pumping stations.

Hydro power
Status quo and trends — In South Tyrol there are more than 700 hydro-power stations with a total energy production of more than 5 300 GWh per year (Province of Bolzano, 2008). At the moment there is a boom in hydro power, largely due to the green certificate (an Italian CO_2 compensation certificate) which makes up to 40 % of the economic profits of hydropower providers.

Hydropower depends directly on precipitation and its variation in space and time. In recent years a slight decline in water availability for hydropower has been recorded. The years 2005–2007 were particularly dry, which caused a loss of revenue of 10–15 %. The projected decrease in summer precipitation would not necessarily have had a strong negative effect, as under the current conditions during the summer months there is a great deal of surplus water. A potential future problem is the expected increase in heavy rain events, during which power production is often not possible (due to heavy sediment and debris loads). According to the hydropower providers, it can be generally assumed that even under climate change, more power will be produced in South Tyrol than is required.

Adaptation — Even if water shortage and climate change are not the main drivers of adaptation in the hydropower sector, some adaptation measures have already been carried out by the energy providers that take these aspects into account. Amongst other measures there is investment in the construction of reservoirs and pump storage power plants. To be able to make use of heavy rainfall, reservoirs have been specifically constructed to retain water, including sedimentation basins. To solve conflicts with agriculture on a local level, some hydropower providers have informal arrangements with farmer's associations to provide water during peak demand for agriculture, particular in the time of frost sprinkling. Furthermore, some of the hydropower producers are discussing the possibility of providing subsidies for effective irrigation methods to decrease water extraction by agriculture. To prepare for future challenges, the hydropower sector is also investing in research and development in alternative energy sources like biogas and wind.

Drivers and barriers — Since the efficient use of water in the hydropower sector relies to a large extend on technical solutions, the driver in the past was investment in water storage and adding value. In addition, the CO_2 compensation mechanism of 'green certificates' helped the sector to be economical successful even in times with less water. Furthermore, cross-sectoral collaboration (as well as communication), mainly with the agricultural sector but also (partly) between individual energy providers, can be seen as a driver. A further driver is the political will to invest in alternative energy sources. The province supports, to a large extent, photovoltaic plants, the use of wood for local energy production and the setting up of a hydrogen network.

A major constraint on adaptation is the lack of communication between sectors and also within the energy sector itself. A further technical constraint on the adaptation by the hydropower sector is the limited available space suitable for the construction of new reservoirs. Furthermore the eventual negative side-effects (environmental, loss of agricultural areas as well as build-up area) limit the acceptability of such measures.

Tourism
Status quo and trends — Water scarcity is a minor problem for tourism. Problems with water availability appear mainly in winter in the ski resorts where a slight decrease in water availability coincides with a significant increase in demand. This is due to an increasing number of tourists, an increase in activities requiring water (hygiene) and due to an increasing demand for artificial snow making. Even if the demand for the latter is small compared to overall water consumption (less than 2 % of the total water consumption) water availability is a problem for this activity, since water is needed when it is rare and at places (high altitude) with smaller catchments and small surface water supplies. Water demand for artificial snow has more than doubled in the last 10 years (Abteilung Wasser und Energie, 2008).

Adaptation — The main adaptation strategy in the tourism sector is the setting up of reservoirs for artificial snow making and other touristic uses. The province followed this strategy since the 1980s and made it obligatory to provide at least 700 m^3/ha ski track storage capacity, which is about 1/3 of the water needed per season. An ongoing trend is to build multi-purpose reservoirs, which can be used for agriculture in summer, for artificial snow making in winter and for hydropower throughout the year. Recently the province is working on a reservoir plan, to better coordinate water users and the construction of new reservoirs in the province.

A further adaptation measure is the introduction of innovative artificial snow making methodologies. At the moment the tourism sector is very active in looking for appropriate adaptation measures for winter tourism and is organising workshops and expert meetings on this topic.

Drivers and barriers — The main driver is the cross-sectoral planning of water use by applying the water use plan and by developing the reservoir plan. Other drivers are the technical efforts put into water management and the construction of new reservoirs to support the continuous provision with water.

One of the constraints on adaptation is that water saving in tourism is not a very prominent issue. A further constraint is the rising demand for water. One of the biggest barriers to adaptation in the case of winter tourism in South Tyrol is that the region relies to a large extend on snow and winter sport and that almost none of the stakeholders can imagine winter tourism with less snow or without snow.

5.5 Savoy — balancing water demand and water supply under increasing climate change pressures (France)

Summary

The Department of Savoy (for its location, see Figure 5.1) has a complex topography with many high altitude mountain chains and a wide range of climatic zones, from sub-Mediterranean and oceanic to dry inner alpine valleys. The available water resources are very variable and, depending on their surface and groundwater storage capacity, are sensitive to climate change and human impacts. Whereas traditionally, local water supply from springs was sufficient for local populations, nowadays this supply is increasingly temporally and spatially limited due to new pressures arising from expanding communities and the temporary influx of tourists. Thus, although some regions of Savoy are primarily experiencing water demand problems, these are being exacerbated by a combination of supply limitation and climate change impacts.

The main adaptation activities are as follows:

- technological solutions, including inter-basin pipeline transfer and groundwater pumping;
- sharing of water for snow-making from hydroelectric reservoirs;
- construction of new reservoirs for tourism-related water needs;
- water purification (desulphurisation) to ensure water for communes;
- inter-communal water sharing.

Since the increased seasonal uncertainty of snowfall and precipitation has increased concern about the reliability of natural snow and water supply, the main form of adaptation has been through technological solutions. There is a need to move from shorter-term technological to longer-term water demand management solutions.

The following adaptation strategies seem promising to deal with changing water resource issues due to climate change impacts:

- implementation of a 5-year water management plan for the Isere river basin to ensure the sustainable development of water resources;
- development of more drought-resistant agricultural crops, water re-use and water management recommendations (e.g. in the framework of the European AlpWaterScarce project);

To conclude, the main lessons that can be learnt from the case study are:

- the establishment of a more intensive monitoring network would enable a more precise determination of the water balance. This should include the homogenisation of long time series of high temporal resolution, including seasonal variability;
- more accurate data on water abstraction would enhance transparency for different water users;
- better knowledge of qualitative and quantitative impacts of water abstractions on ecosystems is important for the future. Here reference data sets of non-impacted watercourses would be essential;
- optimal ecological flow should be identified, quantified and respected, since the water cycle is increasingly impacted by long term and long range transfers between river basins and from valley bottoms to peaks;
- extensive adaptation policies are required to sustain winter tourism in the face of climate change impacts, including economic diversification measures.

Photo: © European Environment Agency

5.5.1 The region and its water resource issues

Geography

The Department of Savoy is situated in eastern France along the western range of the Alps. Its major rivers, the Arc and the Isere, drain into the Rhône. It has a surface area of 6 028 km², consisting of more than 75 % mountainous terrain. It includes two inner alpine dry valleys, that of the Arc (Maurienne) and that of Isere above Albertville. Its altitude ranges from 200 to 3 600 m. Vegetation includes mainly forest (35 %) at lower altitudes below 2 400 m and a dominance of bare surfaces (22 %) and pastures (21 %) in the upper belts (1 500–3 500 m) with 2.4 % glaciated areas in the zone above 2 700 m. Less than 3 % is urban with only 2.2 % agricultural, 0.1 % wetlands and 1.3 % lakes and torrents (Keller and Förster, 2007). Seasonal snow cover plays an important role for seasonal hydrology (de Jong *et al.*, 2008); snow covers 3 % of the department all year round and about 25 % of it for 3 months of the year. The main agricultural activity is milk production and cattle farming. Some heavy industry still exists. Savoy has numerous dams, mainly for hydroelectric production. Nearly 25 % of the department is unproductive from an agricultural point of view. However, economically, the area is well exploited for summer and winter tourism, with approximately 30 million nights per year. Tourist bed intensity reaches 5 000 per 1 000 inhabitants in ski resorts such as Val d'Isere and La Plagne. Savoy has 400 247 inhabitants living in 330 municipalities. The population density of 66 inhabitants per km² for the region is only an average value, showing that large areas are sparsely populated, in contrast to the densely populated valleys. The unemployment rate is between 6 and 10 % and the gross national product lies at around EUR 24 500 per inhabitant (2004). Hydroelectric production is a major issue in the upper valleys.

Water resources and climate change

The Department of Savoy has a complex topography and climate that includes a dry southern sub-Mediterranean zone with several dry inner alpine valleys and a wetter west oceanic zone. The average annual temperature lies around 10.3 °C and average rainfall is 1 136 mm. Drier valleys such as Bourg St. Maurice only receive 971 mm rainfall and are nearly comparable to the Valais. However, depths of snow greater than 4 m are common at the highest altitudes above Bourg St. Maurice. Strong, dry foehn winds can occur in the winter. The uppermost parts of these mountain catchments do not store or produce water in large quantities, especially in the winter. The hydrology here is very complex, with large, virtually arid scree fields, whose flow is subsurface and thus protected from evaporation, occurring right next to small stagnating zones such as wetlands and streams. Groundwater is limited since aquifers are fractured and dispersed into many small niches, and so capable of storing much less water than the large porous aquifers commonly associated with the plains.

Concerning climate change, there has been a severe increase in temperature of the order of approximately 2 °C in the Belledonnes mountain chain in the past 20 years alone. Although the variability is high, snow depth has decreased on average from 8 to 4 m in Bourg St. Maurice and from 4.2 to 3.3 m on average in St. Martin de Belleville over the last 30 years. Like the rest of the Alps, any temperature increase is expected to have major effects on glacier volume, snowline altitude (150 m increase in snowline altitude with every degree of warming), and the relations between snowfall and rainfall.

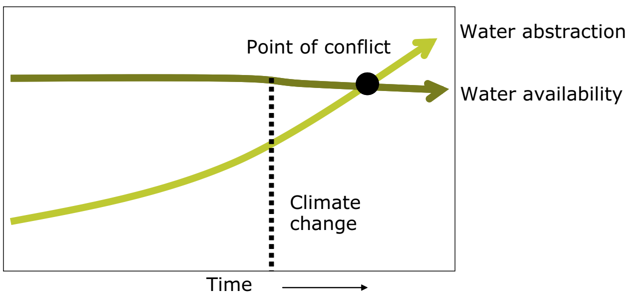
Seasonal distribution of rainfall is variable. Over the last few years, June and September have become significantly drier and August and October wetter. On the whole, there has been a decrease in total precipitation. Dominant snow-melt is from April to June. Glacial melt starts around June and lasts until August. The highest discharge is expected in July and August. The average winter discharge, from December to April, is 30–50 times lower than in summer. The regeneration of groundwater has not been monitored in detail over the long term but the dynamics of springs in karstic areas over the last few years indicates that the groundwater reservoirs are very sensitive to climatic conditions and do not have much long-term storage capacity. Thus several springs dried up in Savoy during the last few heatwaves since 2003. In some areas this has threatened the agricultural productivity of cattle farmers both due to the direct shortage of drinking water for cattle as a result of drying up of springs and due to the reduction in good quality pasture as a basis for cheese production (de Jong *et al.*, 2008).

Apart from the natural variations in discharge, there are also strong local anthropogenic influences, caused by water diversion and temporary or permanent water storage. The main man-made influence on discharge is by large dams, some of which tap more than 50 % of the available water resources. The remaining water is abstracted for irrigation, potable water and snow production. The seasonal variations and differences in water consumption for different alpine cities are very large, depending on whether they are touristic or not. Some higher altitude ski tourist resorts count more than 50 000 overnight stays in winter (Keller and Förster, 2007). The maximum drinking water demand generally occurs during the month of December, coinciding with the highest tourist numbers of the year. With a tourist population 5 times higher than its permanent population over the Christmas period, the ski resort of Bourg St. Maurice (permanent population of 6 750) for example, consumes triple the amount of water in December. The relative annual water consumption of a ski tourist resort is on average 1.5 times higher than that of a non-ski resort. Therefore it is important to compare the hydrological pressure exerted by tourism at different scales. At the sub-catchment scale, the relative amount of water consumed may be much higher than that distributed over the total catchment area. This explains why water conflicts have started to arise at the local, sub-catchment level (see Figure 5.4).

5.5.2 *Adaptation activities and experiences*

Water supply is at times insufficient at the local level and over a seasonal time scale. This is due to the limited surface and groundwater supply in the smaller sub-basins. Whereas in former times all water could be tapped from local springs, this is no longer sufficient for the growing demands of tourism, including potable water supply and artificial snow production during peak consumption times. Thus new solutions have to be found. Water is extracted on an increasingly permanent basis from a combination of sources — streams, small snow water storage reservoirs, hydroelectric dam reservoirs, groundwater, springs, drinking water networks — and has to be transported over increasingly long distances. This water transport includes not only inter-basin transfers but also pumping water to higher altitude basins from lower altitude basins where it is more plentiful. In several locations, in particular in the dry inner alpine valleys, water has to be stored in advance in local intermediate storage tanks and reservoirs during the summer for snow-making before and during the tourist season.

Figure 5.4 Climate change and water conflicts



Source: Carmen de Jong, 2009.

From a hydrological point of view this is not without repercussions, since the ecological and agricultural water requirements downstream of the water abstraction points and intakes will be temporarily affected by these water diversions, in particular in the winter months when there is naturally low discharge. Normally, water is diverted and stored when it is most plentiful. However, taking into account that these requirements are steered by human needs and are strongly influenced by adverse climatological factors such as high winter temperatures, warm foehn winds or lack of natural snow, it is probable that water abstractions coincide with those periods of the year where water discharge is lowest. Also, since run off in mountain catchments is predominantly subsurface at higher latitudes, the trend towards storing water at the surface at high altitudes in storage tanks and reservoirs impacts the seasonal variations of flow and increases vulnerability to water loss by evaporation. Water diversions affect the local water cycle over time and space. To what extent changes in the water cycle can affect ecology still has to be investigated, in particular with respect to drought resistance. It is clear, however, that water diversions for the benefit of a tourist population of 10 000, for example, cannot be without effect on local torrents and groundwater recharge.

Water quality is an important element in water supply, which is often directly related to water quantity. The need to supply local peaks in water consumption requires the availability of drinking water quality all year round. Thus, water purification e.g. by desulphurisation can contribute to extra water availability. Also, water quality can be adversely affected by long pipeline diversions and long transit times in reservoirs.

It is estimated that there is a high vulnerability to water shortages developing at the local scale if no technological solutions emerge. For example, if all taps are open for water consumption on a daily or weekly time scale during a warm and snow-deficient winter, (i.e. for drinking water, hydroelectricity and artificial snow production), this could lead to a complete drying up of the local water resources, mainly torrents downstream of the abstraction points (APTV, 2008). The main problems concern the maintenance of minimal ecological flow (for ecology, tourism etc.), the estimated water loss due to evaporation associated with artificial snow production (Arabas *et al.*, 2008), the modification of seasonal flow regimes due to artificial snow production (de Jong and Barth, 2008) and the danger of a simple spatial transfer of water problem from upstream to downstream. Water-related conflicts of interest are very rare. However, as in the Valais, different sectors are facing various problems related to water resources or climate change, mainly at the local level.

In Savoy, cross-sectoral and inter-regional adaptation strategies are already practised. These are mostly technical, including inter-basin water transfer, water sharing contracts with EDF (Electricité de France, French Electricity Company) dam reservoirs, tapping of wells, groundwater pumping, construction of water storage reservoirs, construction of artificial snow storage ponds, water purification and inter-communal water sharing. Inter-basin transfers tapping springs and redistributing water over altitudinal ranges exceeding 1 000 m are common in order to fill intermediate reservoirs and artificial snow ponds. In other locations water treaties with EDF are being implemented to obtain water supply from hydroelectric dam reservoirs where supplies from local springs and groundwater are insufficient. Compensation is paid to EDF for any loss of electricity production.

The major adaptation constraints related to climate change include decreased water availability during dry summers due to reduction in spring and surface discharge, increased water losses due to increasing evapotranspiration, and decreased water quality during hot summers. Technological constraints include possible pipeline damage when water is transported over long distances. Economic constraints include rising electricity and water prices and the related rising costs of artificial snow production. Other constraints are related to an inadequate and incoherent knowledge and data base, in which the surface and groundwater monitoring network is incomplete and there is insufficient long-term or seasonal information, for example. The absence of clear quantitative data on water abstraction can also hinder the willingness for water sharing between different water users. The lack of knowledge on the qualitative and quantitative impacts of water abstractions on ecosystems reduces the responsibility for water sharing between economic and environmental needs.

However, climatic and anthropogenic change also bring with it several new adaptation opportunities; one of which is the development of a clear overview of water availability and requirements for different users. This is optimised through the implementation of 5-year water management plans, such as that for the Isere river basin in Tarantaise. Control of agricultural water consumption is another opportunity, and includes issues such as the development of more drought-resistant agricultural crops, water re-use and water management recommendations. Development of water saving methods at the household level could also prove useful during peak consumption times. These approaches are to be developed in the framework of the European Alpine Space project, AlpWaterScarce, coordinated by the Mountain Institute in the Department of Savoy. Its overall aims are to develop water management strategies to counter water scarcity in the different alpine countries. Other opportunities include the development of less water-intensive tourism, the diversification of tourism to attract visitors all year round and the development of alternatives to skiing in winter (see European Alpine Space project — ClimAlpTour). Technological solutions are also possible, for example through better water storage.

Photo: © European Environment Agency

5.6 The secrets of Vienna's high water quality (Austria)

Summary

The karstic mountains Mt Hochschwab, Mt Rax, Mt Schneeberg and Mt Schneealpe play a vital role in the water supply of 2 million people, including the City of Vienna. The main water resource issues in the region of the case study arise from the specific geological features of karstic mountains (e.g. short time span between infiltration and discharge of water after an event), from climatic parameters (e.g. rising temperature) and from land-use activities (e.g. farming, forestry), which substantially influence water quality.

Up to now, reasons for initiating adaptation activities have been driven by concrete effects and socio-economic impacts rather than climate change predictions and/or scenarios. Climate change effects are only little recognised in the water planning and management process, mainly due to the lack of a sound knowledge base about the impact of global warming on water resources at the local and regional level. This in turn impedes decision-making with regard to water management under uncertainty. However, adaptation to current water problems has been successfully managed so far by the competent authority within the City of Vienna, the Viennese Water Works.

In particular, the following adaptation activities proved successful:

- clear legal framework and strong commitment of policy decision-makers to secure water resources;
- cross-sectoral coordination between different land users;
- personal contact between the water supplier and the local population;
- sound data collection.

Future climate change makes it likely that water availability will change, for example by an increased number of extreme events, which might cause more frequent water turbidity resulting from high rates of mobilised sediments. Adaptation measures to meet these future conditions are already under discussion and some concrete measures have been planned. The following additional adaptation activities seem promising as a way to deal with the changing water resource issues due to climate change impacts:

- further research activities and knowledge transfer to reduce uncertainties in relation to climate change impacts;
- development of planning and management tools that consider climate change effects (e.g. including climate change aspects as decision criteria into the existing Decision Support System).

To conclude, the following main lessons can be learnt from the case study:

- intensive data collection is needed to improve basic knowledge of the whole system and to properly inform decision-makers about adaptation management;
- planning for water management strongly requires cross-sectoral considerations that take into account ecosystem services and pressures from land use;
- proactive information, intensive personal contact and involvement of the local population in water management issues (e.g. as employees) improve the acceptance of adaptation measures;
- activities to provide technical as well as financial support enhance the success rate of measures taken.

5.6.1 *The region and its water resource issues*

The North-Eastern Calcareous Alps of Austria are of crucial importance for the drinking water supply of 2 million people in the cities of Vienna and Graz and other communities in Lower Austria and Styria. The water resource issues in the case study area are mostly related to water quality issues. Because of this the springs in the region are legally protected and the surrounding area is secured within a certain distance by so called sanctuary zones ('Schongebiet'). The water sanctuary zone for all of the 31 springs providing drinking water for Vienna is owned to a large extent by City of Vienna. It comprises the mountain massifs of Mt Schneeberg, Mt Rax, Mt Schneealpe and Mt Hochschwab. The karstic mountains range in height between 450 m and 2 277 m. The climate of the water protection zone is humid and influenced by the Atlantic Ocean (Curry and Mauritzen, 2005 in Köck *et al.*, 2006). Mean annual temperatures are approximately 6–8 °C in the valleys, decreasing to 0–2 °C in the summit region. Annual precipitation averages 700 mm (valleys) and 1 500–2 500 mm (peaks).

In comparison with other water resources, karstic aquifers in mountainous areas have maintained high water quality up to the present time. Nevertheless, they are extremely vulnerable due to a combination of geological characteristics, climatic parameters and land-use activities, which together substantially influence the hydrological characteristics and thus the quality and quantity of the water available.

As a result of the specific geological features of karstic rocks, there is almost no surface run-off. The precipitation percolates through the surface layers, circulates inside the mountain and after reaching impermeable layers drains to springs, whereby it returns to the surface. The time span between infiltration and the discharge of water after a rainfall event is very short and therefore there may be less purification of the water as it passes underground than is the case with other groundwater systems. Extreme events, such as heavy rainfall or rapid snow melting, mobilise large amounts of sediments and cause water turbidity which cannot be filtered out within the short time before discharge. Another characteristic of karstic springs is their unsteady delivery, which requires careful management based on sound information about the springs.

Changing climate conditions, such as rising temperature, will influence the availability and quality of water directly through enhanced evaporation and changed precipitation regimes. But climate change will also have indirect effects on water resources through the altered nature of vegetation. Due to changing climatic conditions, in particular the increase in temperature, there has been an upward movement in the distribution of alpine plants, the composition of the vegetation has changed and treeline species have responded by invading the alpine zone or increasing their growth rates. These effects, combined with other environmental changes such as the higher rate of nitrogen deposition, might influence the filtration function of soil and vegetation and, in turn, the quality and quantity of water. However, the character and degree of such changes cannot yet be estimated with certainty. More research is necessary to predict the direct and indirect impact of future climate change on the availability and quality of the water resources in the case study area with any degree of confidence (Dirnböck *et al.*, 2003).

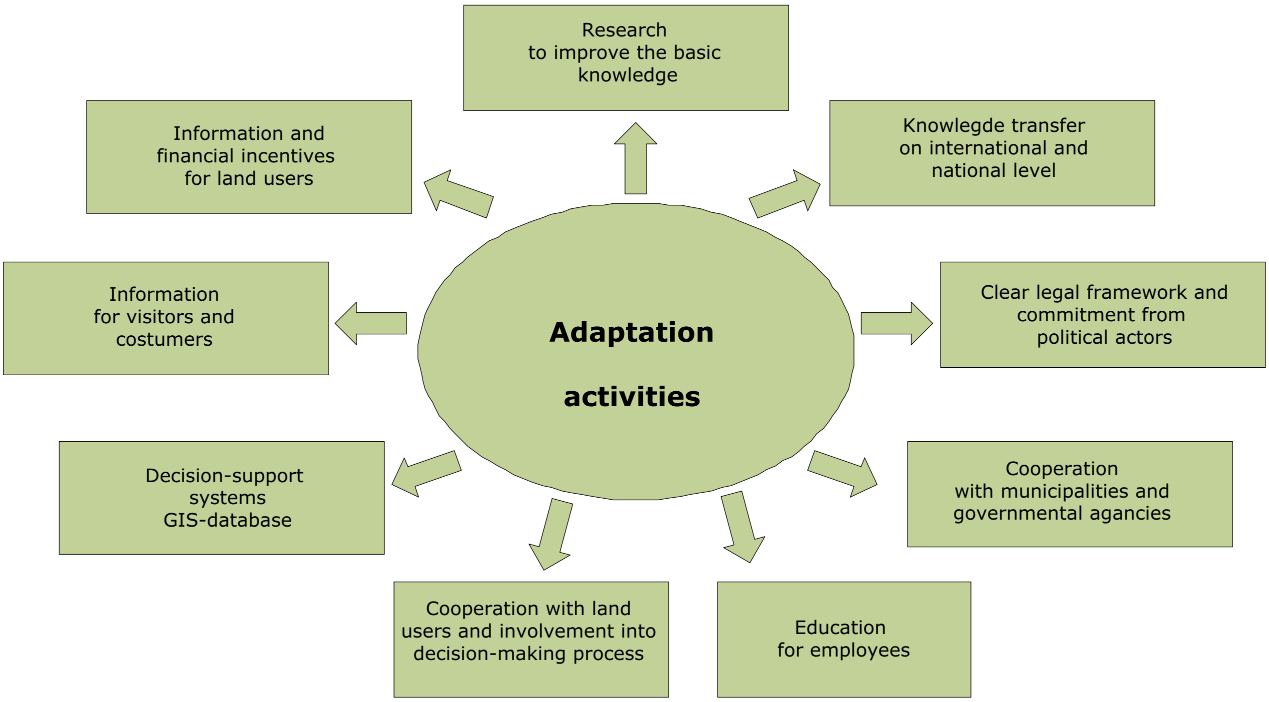
5.6.2 *Adaptation activities and experiences*

Adaptation activities aimed at safeguarding water supply and the natural conditions of the catchment areas are mainly responses to problems caused by the geological characteristics, climatic parameters and land use activities. Climate change is only one additional aspect here. The following section presents firstly, adaptation activities and experience in the field of water supply, and secondly, adaptation measures implemented in the forestry, alpine pastures and tourism sectors. The adaptation activities presented here (see Figure 5.5) have largely been initiated, conducted and coordinated by the Viennese Water Works, which is the competent authority within the City of Vienna for all water supply related issues. The following information on adaptation activities and experiences is based on interview results and outcomes from the KATER project.

Water supply

The interviewees stated that a clear legal framework (e.g. Austrian Water law, European Water Framework Directive) and a strong commitment from policy-making actors are highly important preconditions for securing the water resources in the case study region. In addition, high quality water can only be assured in the long term by adequate land use practices, which require two approaches: precautionary protection and rehabilitation measures. As a precautionary protection measure, the City of Vienna has been protecting the Vienna Springs for more than 130 years, gradually gaining ownership of vast territories in the water protection and sanctuary areas. The water protection zone covers an area about 970 km² located in Styria and Lower Austria. Two thirds of the protection zone is

Figure 5.5 Adaptation to water resource issues in Vienna's water mountains



Source: ETC/ACC, 2009.

covered with forests. Today, the City of Vienna owns one third (32 600 ha) of the water protection zone. For this municipal land, the Viennese Water Works and the Municipal Department of Forestry are the key decision-makers together with the regional governments of Lower Austria and Styria. Imposing a ban on any activities in this area would not necessarily best serve to protect the water systems. Land use activities like forestry, environmental protection and sustainable tourism can support the goals of water protection if performed adequately. However, karstic areas often have a certain economic value and experience pressures from different land users, such as agriculture or tourism. For this reason, rehabilitation measures such as improved information and integrative management tools had to be developed and implemented.

In the case of water supply, a sound information base about the natural system and land use activities is recognised as a crucial precondition for developing reliable adaptation activities. For this reason, intensive research is undertaken by the Vienna Water Works to minimise uncertainties and to enhance understanding of the whole system. Furthermore, transfer of knowledge related to water supply in karstic areas is accomplished on international and national levels as well as within the organisation. The Viennese Water Works has recognised that the education of their employees is a key factor for successful implementation of adaptation activities. Information gained through research projects and scientific studies is actively communicated to the people working in the field, which in turn enhances the acceptance of research outcomes. However, information is also provided to the general public. 13 years ago, the Vienna Water Works opened a so-called Water School ('Wasserschule') for school children and other interested persons. Visitors are provided with related informational material, e.g. about the water supply system of Vienna or about water saving measures.

In the course of research, climate change issues have not so far been investigated in detail. For the Vienna Water Works, gaining information is an ongoing process and will be continued and extended for the issue of climate change in the future. This will be accomplished, for example, by involvement in research projects on an international level.

Integrated water resource management has to balance requirements to protect springs with the demands of a variety of land use activities. The main objective of the KATER project was the development of a (Spatial) Decision Support System ((S)DSS) to handle key tasks of water management — administration, crisis management and planning. In general, the (S)DSS integrates a broad range of practical experience of stakeholders with formal knowledge of experts, helping to make the decision processes more effective and transparent. The results cover a wide range of land-use conflicts and different preconditions for decision-making (national legislation, spatial dimension, and data availability).

The (S)DSS is not completely implemented as yet. The delay was partly caused by problems related to the collection and management of the large amount of data required by the system. Furthermore, no information about the impacts of climate change has been included so far, which might be a barrier to successful adaptation in the future.

However, the success of all adaptation measures mentioned above can mainly be traced back to the fact that all relevant stakeholders are strongly involved at different stages of the planning and implementation process. This is also a key factor in relation to the various land use activities that are taking place in the water protection zone.

Forestry

Due to the wide variation in altitude and the geological diversity of the case study area, several forest communities can be found within the water protection zone (Köck *et al.*, 2006). Forestry has a long history within the water protection area of the City of Vienna. Due to the clear-cutting practise of the past century, some areas are homogeneous coniferous stands and not structured. These stands are characterised by high vulnerability with regard to natural hazards, snow damage or insect calamities. However, the forest in the case study area fulfils essential functions for water protection and for balancing the hydrology of watersheds. On this account, forest management within the water protection and sanctuary zone follows the overall purpose of drinking water protection. Based upon the knowledge gained by data gathering and by the collection of international scientific literature, guidelines/forest management plans have been defined for forest practice in the protection area and sanctuary zone. Furthermore, a GIS model has been applied to detect those forest stands which do not have an optimal tree species distribution with regard to water protection. The transformation of homogenous conifer plantations into mixed stands, taking the potential natural forest community into account, can be regarded as one of the main challenges affecting water protection in forestry. This can be achieved, for example, by using a small patch cutting system and limiting timber extraction to 15–20 % of stand volume (Köck *et al.*, 2006).

Alpine pastures

Alpine pastures have a long history in the area. Summer pasturing in the area from June to September dates back at least to the sixteenth century. Since the mid-19th century, alpine farming in the area has declined and much of the former pasture land has been abandoned. In general, the intensity of land use is low, but spatially variable: the area close to alpine huts is more intensively used than remote parts of the mountain pasture (Dirnböck *et al.*, 2003). Approximately 30 % of the subalpine and alpine zone of Mt Schneeberg, Mt Hochschwab, Mt Schneealpe and Mt Rax is still pastured by free-ranging cattle at an intensity of ca. 0.5 cattle per hectare (Dullinger, unpublished data, in Dirnböck *et al.*, 2003). The main impact alpine pastures have on the karst water system is the potential input of faecal bacteria from cattle and sheep into the groundwater system. On this account, the Vienna Water Works are supporting farmers financially, for example, by assisting them to install proper watering places for their animals to keep them away from springs and sinkholes.

Tourism

Tourism also plays an important role in the area, mainly because of its close proximity to Vienna. Mt Rax and Mt Schneeberg are highly frequented destinations for day-trips and are still gaining in popularity. In the field of tourism, the presence of alpine huts generates negative effects when the disposal of faeces, waste water and waste is not appropriately handled. In these cases, the introduction of human faecal bacteria poses a potential risk to drinking water quality. To safeguard the quality of water, the Viennese Water Works are involving stakeholder groups, such as

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alpine associations, to serve as multipliers to raise awareness on the issue of water protection among a larger group. This is mainly achieved by aiming for cooperation. For example, in collaboration with the alpine association, visitor management was improved by reconstructing and re-marking existing trails. Furthermore, information about the sensitivity of the water protection zone has been provided by installing nature trails or publishing flyers for distribution. Moreover, the Viennese Water Works are offering financial incentives for certain activities, such as for hut owners to improve their waste water treatment. Sewage pipes bringing the faecal waste and waste water to the valley outside of the catchment areas for further treatment have been constructed with financial, technical and organisational support of the City of Vienna.

To sum up, all activities initiated so far by the Viennese Water Works in cooperation with other land users have proved to be effective in terms of safeguarding the drinking water supply in quantity and quality. Intensive two-way communication between land owners and governmental institutions as well as sufficient financial support can be seen as decisive factors for successful adaptation in the past. Nevertheless, climate change effects have only been marginally considered in the adaptation process so far. There is already an awareness of the need for flexible adaptation strategies to cope better with future uncertainties within the Viennese Water Works and the City of Vienna. On this account, further research and data collection, including knowledge on climate change will definitely be accomplished in the future.

5.7 Is there a need to prepare for potential droughts even in the Soča river basin? (Slovenia and Italy)

Summary

The Soča River is 136 km in length, of which 95 km lies in Slovenia and 42 km in Italy (for its location, see Figure 5.1). Its source is at 1 100 m altitude in the Trenta valley in the Julian Alps, and it flows through a reasonable straight course to the Adriatic Sea. The Soča provides a good example of transboundary river management. The Slovenian part of the Soča river basin is not only one of the wettest parts of Slovenia, but also of Europe as a whole. Therefore the main focus in this region is on heavy precipitation episodes, related flash floods, debris flow and landslides. Historical records also show that these have been the main problems in this region in the past and in view of the future increase of extreme events it is expected that these pre-existing threats will become even more significant. Drought is unknown in the Upper Soča valley because precipitation is frequent, but in the southern part of the basin drought sometimes occurs. In the southern part and in particular in the Italian part of the basin, precipitation is less abundant and water consumption is much higher. Due to hotter summers and higher evapotranspiration the need for water in the southern part of the basin is expected to increase. The Italian representatives to the bilateral Slovenian-Italian Commission in the field of Water Management have already requested more water, especially during periods of drought.

The following adaptation activities to address consequences of drought and heavy precipitation have proved to be successful:

- a clear legal framework and strong commitment of politicians to share information and coordinate decisions and measures to be taken against threats caused by erosion, landslides, debris flow, drought and floods;
- a cross-sectoral approach when preparing the scientific basis for decision-makers and politicians;
- personal contact between politicians and experts from both countries sharing the river basin helps to speed up the process of recognising the problems specific to one country and the process of searching for appropriate solutions for both parties.

It is expected that water availability will change due to future climate change, because of an increased number of extreme events that might cause floods and landslides in the upper river basin, and more frequent drought episodes in lower part of the basin.

The following main lessons can be learnt from the case study:

- intensive data collection and exchange between stakeholders in the whole river basin is needed to improve the basic knowledge of the whole system and to optimise decision-making in terms of sustainable river management and adaptation to climate change;
- international commissions and expert groups including both politicians and experts help to ensure sustainable water management in the whole river basin when the water basin extends over the territory of more than one country. All involved countries benefit from proactive information exchange and coordination. Enhanced communication between different stakeholders plays a crucial role;
- climate change threats can vary significantly from one part of the basin to another. While the upper part of the basin is threatened by heavy precipitation and consequently floods, debris flows and landslides, the lower part can suffer more due to drought episodes. Alpine rivers are important sources of water for lowlands where far less precipitation falls and with the expected increasing drought frequency in lowland regions the importance of alpine rivers as water sources will increase;
- communication has to include politicians, experts, NGOs, local people, and stakeholders from different economic sectors in order to ensure the development of efficient and sustainable water management tools.

5.7.1 The region and its water resource issues

Geography and climate

The interaction of three major climate systems (continental, alpine and sub-Mediterranean) influences the precipitation regime in the territory of the Soča river basin. The spatial variability of precipitation is high — total annual precipitation varies from 1 100 mm in the coastal part of the river basin to more than 3 500 mm in the Julian Alps — corresponding to one of the alpine precipitation maxima. The spatial distribution of precipitation is highly influenced by the complex terrain. Due to an orographic effect the Julian Alps and the Dinaric barrier receive the highest amount of precipitation in Slovenia (Cegnar *et al.*, 2006). The largest amount of precipitation is brought by wet south-westerly winds blowing from the Mediterranean and crossing the high Dinaric-Alpine barrier. Most of precipitation falls on the upwind side of this mountain ridge.

The highest daily precipitation (above 400 mm) has been recorded in the region of Posočje (Upper Soča river basin). During the warm part of the year, strong showers are also frequent, and it has been estimated that precipitation of more than 100 mm in one hour is possible (Cegnar *et al.*, 2006). Due to the very pronounced variability and, by definition, rare occurrence of weather and climate extremes it is difficult to assess trends and long-term variations. The time between two occurrences of one particular extreme event in a certain area may extend over a period of several years. All extreme events observed to date will continue to occur in the future; in view of the expected impact of climate change on extreme weather it is likely that both intensity and frequency of extreme events will increase.

The possible synergistic effects of various components of the climate system and the environment also need to be taken into account. Extremes have always represented a threat to society and the environment. With such a varied climate as that of the Soča river basin, extremes have various impacts and their consequences involve different aspects. Torrents and floods are a direct result of heavy precipitation which may, however, also cause a series of other harmful events such as soil erosion, landslides and material deposits onto fields and pastures. The intensity of events that cause significant damage is not uniform throughout the territory, and so thresholds for each region should be set separately. For example, there are almost no differences between regions as regards short intense precipitation lasting from several minutes to several hours, but there are outstanding differences in daily and multi-day extreme precipitation events among different parts of the river basin.

Even more important than annual trends are seasonal variations due to climate change. The annual cycle of precipitation depends strongly on the major climate system that influences a specific region. In the Mediterranean region there are two maxima — in late spring and in autumn. In the Alps the most pronounced maximum precipitation is in autumn. Precipitation measurements are underestimated, especially in high and exposed mountainous regions. In Slovenia, precipitation is measured with a Hellmann-type rain gauge, which underestimates precipitation, especially in periods with strong winds. For the water balance and for other purposes precipitation measurements are corrected for systematic measuring errors, of which the largest is wind-induced error (Kolbezen and Pristov, 1998).

One of the extreme phenomena that causes a great deal of damage, above all to arable farming, is drought. Although on average there is enough annual precipitation, there has been a severe summer drought four times during the last 15 years in Slovenia, although this has not yet happened in the Upper Soča river basin. Yet the karst and Italian parts of the Soča river basin especially are potentially threatened by summer drought. An artificial lake fed by the Vogršččk (Zadrževalnik Vogrščček) spring in the Vipava valley (the Vipava is a tributary of the Soča) has existed for a couple of decades to provide water for irrigation to local farmers.

An important factor in planning for adaptation is the fact that part of Upper Soča valley is in a national nature reserve (the Triglav National Park) and therefore land-use changes and interventions that would damage the natural environment are heavily restricted. Additional territory belongs to Natura 2000 and it is also subject to some constraints regarding land use and human-induced changes to the environment.

Climate change and scenarios

Changing climate conditions, such as rising temperature, will influence the availability and consumption of water; evaporation is expected to increase and the precipitation regime is expected to change. Snow cover in the mountains could melt earlier in the season, lower altitudes could get less snow due to the change in ratio between solid and liquid precipitation. Therefore, the river regime might also change to become more rain-driven rather than snow-driven (Kolbezen and Pristov, 1998). Climate change will also induce other environmental changes (e.g. erosion, vegetation, and soil and water pollution during flash floods).

Extreme events represent a major burden on the environment and the climatic analysis of such events is a necessary precondition for assessing damage and for all interventions in space (threat risk, planning etc.). Regular monitoring and analysis of extreme events is important as a means of establishing climatic changes. At the same time, data on the intensity of extreme events provide the necessary basis for assessing the damage that such events cause. Such information is a necessary input to any sustainable spatial planning and other decision-making.

Normally, extreme events that cause damage receive the most attention. In such cases, it is not necessary for any meteorological variable to achieve an extreme value. During droughts, for example, it is not necessary for lack of rain to be exceptionally severe, it is sufficient for rainfall to be unusually low for the time of the year in which it appears. How a specific extreme weather event affects the environment, therefore, depends on a range of factors — from the adaptability of the environment, the time in which the event occurs, to the weather in the previous period etc. An increase in the intensity and frequency of extreme events is considered to be closely related to climate change.

In summarising, it might seem that the region under consideration in this study is particularly endangered by extreme weather events but fortunately these are quite rare and achieve a destructive force only in a very limited area. However, this might change in the future.

Up to now precipitation trends in the Julian Alps within the Upper Soča valley have not shown a significant decrease as projected by climate change scenarios, although this might change in the future. Temperature shows a clear increasing trend. In the lower part of the Soča river basin, however, a decreasing trend in precipitation is already apparent, and water consumption may increase in future, not only due to increasing mean temperature and increasing sunshine duration, but also due to human activities and changes in water use.

5.7.2 Adaptation activities and experience

The need to adapt to climate change has been recognised in Slovenia. The Ministry for Agriculture, Forestry and Food prepared a strategy for the adaptation of Slovenia's agriculture and forestry to climate change (Kajfež-Bogataj *et al.*, 2008), which the Government adopted at its session of the 18th June 2008 (Government communication office, 2008). Climate projections are mostly based on the PRUDENCE project (PRUDENCE), and impacts on the PESETA project (PESETA). An operational plan is still to be developed. A Regional Drought Centre for South-Eastern Europe (DMCSEE) operates within the framework of the Environmental Agency of the Republic of Slovenia; both WMO and UNFCCD contributed significantly to its establishment. The DMCSEE mission is to coordinate and facilitate the development, assessment, and application of drought risk management tools and policies in South-Eastern Europe with the goal of improving preparedness for drought and reducing drought impacts.

Focusing again only on the Soča river basin, it is evident that Slovenia's main concern is heavy precipitation (Gabrielčič and Mali, 2007), whilst drought is an important issue for Italy. The existing bilateral commission and its activities are a good starting point from which to address water management and water availability issues, especially in view of future changing environmental (climatic) conditions.

Adaptation activities to safeguard water supply and the natural conditions of the catchment areas are mainly responses to problems caused by the climatic parameters and land-use activities and climate change is only one additional aspect of these.

Tourism
Tourism is the most important economic activity in the Upper Soča valley. During winter, skiing is the dominant sporting activity in the region. The Kanin Ski Centre is the highest ski resort in Slovenia with slopes starting at 2 300 m. As a result of cooperation with neighbouring Italy, established in 2008, Kanin Ski Centre is connected with Sella Nevea, an Italian ski resort. Because of its altitude and connection with the Italian area, which is less exposed to the sun, it is among those Slovenian ski resorts which are expected to suffer least as a result of climate change. During summer, when there is no snow, alternative tourism activities are offered in the mountain area, including hiking, mountain biking, alpine climbing, paragliding and caving (several beautiful, challenging caves).

In summer, rafting and other activities based around the Soča river prevail, but hiking and alpine climbing are also very popular and attract many tourists to the region. Fishing is also an important tourist activity. Climate change is expected to

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extend the season for such activities longer beyond the present peak season and in this respect climate change is expected to have positive effects on summer tourism in the Upper Soča valley, not only due to the longer season but also because more people will aim to spend high summer in the more temperate summer climate of this mountain region rather than in the more oppressive thermal conditions of coastal and city areas. More tourists and a longer tourist season could increase water consumption in the Upper Soča valley.

The region's historical heritage, especially monuments and remains from the protracted battles that took place in the Soča valley during the First World War, attracts a number of tourists. A growing tourist infrastructure will increase water consumption in Upper Soča valley which may lead to water scarcity, but could also potentially have an impact on water availability downstream.

Tourism is also important on the Italian side of the Soča river basin. As well as beach tourism on the Adriatic Sea shore there is a regional nature park, the Isonzo Mouth Nature Reserve that includes wetland, marine and karst environments. The area has been partly naturalised since 1989, when more than 50 ha of farmland were remodelled and flooded, recreating various types of marshlands. Another 150 ha were added from the surrounding area. The nature reserve was established by a regional law in 1996. The reserve has gravel fields and riparian woods as well as plain wood, moist meadows, recently restored freshwater marshes, beds of reeds towards the mouth, sandy and gravel islands, large mudflat areas and sandbanks. The reserve forms part of the Natura 2000 network and is a Specially Protected Area and a Site of Community Importance. The reserve is not far from famous beach and tourist resorts such as Grado (large sandy beaches) to the west, and Duino–Sistiana to the east (beaches in karst area). About 20 km to the west there is the ancient city of Aquileia, founded by the Romans in 181 B.C. The Isonzo Mouth Nature Reserve uses renewable energy resources to meet its own sustainability goals. It attracts many visitors/tourists. Between July and August the Reserve organises the 'Stars over the River', a cultural event which includes music, arts and theatre, dance and literature. The reserve hosts cultural events dealing with environmental issues and linking in with local traditions. At the beginning of September the 'Sagra delle razze' (duck festival) is celebrated in Staranzano.

Hydropower plants

There are already some hydropower dams along the river Soča and another (Avče) is under construction. In addition to the three main hydropower plants there are several smaller ones. The dams could also be used for tourism, and whether or not they could also serve as water reservoirs for more sustainable water supplies needs to be investigated. Although the original dams were not designed for multi-purpose use, it would probably be advantageous if all new infrastructures enabled multi-purpose use. Of course, there is a potential conflict of interest between nature protection and building new water reservoirs, which is why communication between different stakeholders needs to be improved, and why data collection and a scientific basis for decision-making are needed.

Due to the commitment to increase the contribution of renewable energy sources, there is some pressure to construct new hydropower plants; but since large parts of the basin are covered by the territories protected by Natura 2000, and local NGOs are concerned about the protection of the natural environment, plans to build a large new dam on the Soča river do not seem very realistic.

Agriculture

The Upper Soča valley is quite narrow with very steep slopes, therefore agriculture — with the exception of pasture — is not an important economic activity. However, it is important in the lower part of the Soča river basin. Goriška Brda is a hilly region close to Gorica which is famous for its vineyards and wine production and is important economically. Orchards and fruit production are also important in this region, which is very sunny and mild even during winter.

The need for irrigation has already been recognised, but water supplies do not meet current needs during drought periods, especially in the Italian part of the basin. This remains a problem to be solved in future. The Vipava River is a tributary of the Soča to which it joins close to the border on the Italian side. The Vogršček dam, situated on a tributary of the Vipava, was constructed around two decades ago on the Slovenian side of the border to provide water to local farmers for irrigation and spraying of fruit trees during drought periods. This dam has assumed new importance in the light of climate change and some maintenance works are being planned, providing the opportunity to take into account future increased demand for water and enabling multi-purpose functioning.

International cooperation
In addition to several bilateral scientific projects, including analyses of potential climate change impacts on the region, there is also a Permanent Slovenian-Italian Commission on Water Management.

The commission operates on the following legal basis:

- An agreement between SFRJ and Italy, signed in Ozimo, is the basis for the establishment and operation of a bilateral Slovenian-Italian Commission on Water Management.

- A ratification document confirming agreements between the former Jugoslavia and Italy.

The Commission has been in operation since July 1992, holding both regular and ad hoc meetings, the last of which took place in Slovenia on 23 April 2008. Several subcommittees have been nominated by the Commission to deal with specific issues, including water supply, waste water cleaning, monitoring, air quality monitoring and development projects in the two countries' shared water basins. Experts from the Environmental Agency of the Republic of Slovenia are involved in the work of the Commission and subcommittees.

At its last meeting, the Commission expressed a need for more water to be provided to the Italian part of the basin from the Soča River, especially during drought periods. At present there is no more water available. In view of future changes in water consumption and environmental conditions this issue will become even more important than it is today. A bilateral commission is a good basis for a common search for potential solutions. In future, with more pronounced climate change impacts, some conflicts of interest between candidates for water use probably has to be expected, but the dialogue already established between stakeholders (enhanced at a high political level by the Commission) will enable them to search for the best common solutions and will help to establish priorities keeping in mind common benefits.

For this case study the subcommittee on water management in drought situation is relevant. Several institutions are involved in the work of this subcommittee which focuses on different aspects of drought: meteorological, agrometeorological, and hydrological. So far, it has been possible to agree on the threshold for precipitation during drought events. The results will serve as basis for the Commission's work and for decision-making.

An international Interreg project MIRBIS (Management of the International river basin of the Isonzo/Soča) is in progress with the aim of providing a sound scientific basis for common bilateral water management in the Soča river basin.

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6 Adaptation in vulnerable alpine regions — lessons learnt from regional case studies

Key messages

This chapter focuses on the lessons that can be learnt from the case studies in different water-sensitive regions of the European Alps and develops recommendations for future adaptation to water resource issues based on broader empirical research into water management and adaptation to climate change. It specifically addresses the needs and interests of local and regional decision-makers in the Alps who are facing the challenge of adapting to water scarcity and climate change.

The case studies — which are not meant to be representative of the Alps but were conducted to illustrate key issues — highlight that water resource issues in the past appeared in particular locations and at particular times of the year, sometimes resulting in water conflicts during times of peak consumption, which differs partly between different sectors. In most case study regions, water quality is still high; securing high water quality has been an important issue only in some karstic regions, such as Vienna's water mountains. In the future, due to climate change and increasing water demand, an aggravation of water resource issues is expected for most of the regions analysed in this report.

Generally, the case study results highlight the importance of social, institutional and management factors in addition to legal, economic and technological factors. Legal requirements (e.g. EU WFD), economic incentives (e.g. water prices, water markets), the availability of technological adaptation solutions (e.g. drop irrigation) and, especially, concrete water resource issues are important as triggers of and barriers (boundary conditions) to adaptation to water resource issues. However, the adaptation processes themselves seem to depend more on the people involved — their motivation, interests, knowledge, perceptions, competences and the availability of leaders and facilitators — and institutional and organisational factors such as the management of the adaptation process, effective stakeholder participation and the cooperative structures between different sectors, communities, regions and policy levels. Many of these lessons learnt are generic, and are likely to be transferable or used as guiding examples to support adaptation in other mountain regions.

The following recommendations for adaptation to future climate change in water-sensitive regions of the Alps can be formulated:

- The Alps are among the areas most affected by climate change in Europe. However, the Alps have — compared to other mountain areas in Europe — a high capacity to adapt to the impacts of climate change. Therefore, it seems advisable to take this opportunity to implement strategies to adapt to climate change, which would certainly make the Alps a 'pioneer region'. For this purpose an information platform on climate change impacts and adaptation options in the Alps (including impacts on water resources and water management options) would help in supporting regions in their adaptation activities.
- Future water resource management should take climate change scenarios into account as part of a proactive, precautionary, long-term, integrated, participatory and adaptive water resource management approach (stressing the role of Integrated Water Resource Management, monitoring, management under uncertainty and stakeholder dialogue).
- Considering the potential impacts of climate change on water resources and the increasing water demand in sectors like tourism it seems advisable that future water resource management should follow a demand and supply management approach, aiming for technological as well as behavioural solutions. In addition, due to the risk of decreasing water availability there might be a need for more and new forms of cross-sectoral cooperation.
- Due to the probable increasing need for inter-communal water transfer and coordination of water use it seems advisable to organise adaptation to climate change impacts at the regional scale. Regional adaptation strategies allow for the problem-oriented, stakeholder-specific and flexible management approach needed to deal with the uncertainties of climate change. Coordination platforms at a regional scale appear crucial in this context.
- The coordination and information flow between different levels of policy-makers, stakeholders and management need to be improved to ensure sufficient consideration of climate change in EU, national, federal, regional and local policies, legislation and regulations for water resource management ('climate proofing').

Even if the EU goal of stabilising the global mean temperature to 2 °C above pre-industrial levels is achieved through stringent worldwide mitigation actions to stabilise global greenhouse gas concentrations, some climate change impacts — including those on water resources in the Alps — will remain, at least in the short-and medium-term, making adaptation imperative to reduce vulnerability. The vulnerability of water resources in the Alps is increased even more by other developments, mainly rising water demand. This chapter focuses on the experiences of adaptation to water resource issues in the regional case studies included in this report and tries to develop recommendations for adaptation to future climate change in water-sensitive regions of the Alps based on the regional experiences and wider empirical research on adaptation. Water resource issues, political, regulative, economic and social conditions, as well as suitable adaptation measures are very different from region to region. In addition, decisions on adaptation always depend on the goals, interests and values of the decision-makers. Nevertheless, some general recommendations for regional adaptation to climate change can be made, since many of the case study experiences relate to management problems, which are of general importance, such as cross-sectoral coordination. Presumably, every decision maker faces the same process of evaluating the impacts of climate change and designing appropriate adaptation measures in their specific field of interest and region. Most of the recommendations in this chapter are not specific to adaptation to climate change induced water resource issues but are generally applicable to the various impacts of climate change.

6.1 A high adaptive capacity in the Alps

One of the main objectives of this report is to gain some insight into the vulnerability of the Alps with regard to the impacts of climate change, focusing on water resources. Alpine water resources are sensitive to climate change because they depend on snow and glacial melt water in spring and summer as well as on snow in winter. A decrease of snow cover and melt water, in combination with the expected shift in precipitation patterns (mainly a decrease in summer) will change the temporal and spatial pattern of water availability in the future in a way that will create a demand of appropriate adaptation measures in sensitive regions (see Chapter 2).

The case studies on different water-sensitive regions in the European Alps (Chapter 5) highlight the fact that in the past water resource issues appeared in particular locations and at particular times of the year, sometimes resulting in water conflicts during peak times of consumption. In most regions, water quality is still high, only in karstic regions such as Vienna's water mountains has securing high water quality been an important issue. In many sectors water use is not evenly distributed over the year. Therefore, water resource issues arise for some sectors only during specific periods of the year. Whereas summer droughts have a negative effect, especially for agriculture, forestry, biodiversity, hydropower, river navigation and also for households and industry; in winter hydropower (due to the high energy demand for heating) and tourism (due to lack of snow or insufficient water for artificial snow production) are the main sectors affected by these issues.

In South Tyrol, for example (Chapter 5), water resource issues appear in Vinschgau, the dry plateaus around Bolzano in the south-west of South Tyrol and Brixen, in early spring and high summer. Here, water use which depends on surface water is more heavily affected than water use which depends on groundwater, since groundwater acts as a natural storage system to buffer short-term variations. In Savoy, the available water resources are very variable and are sensitive to climate change and human impacts depending on their surface and groundwater storage capacity. Where local water supply from springs was sufficient for local populations in the past, nowadays this supply is increasingly temporally and spatially limited due to new pressures arising from expanding communities and the temporary influx of tourists. In South Tyrol, too, the growing water demand is seen as a bigger challenge than decreasing water availability. The Lavant valley has had to deal with water shortages during hot summers; the same applies for the Valais and the lower Soča river basin. Water quality problems are mainly addressed in the Vienna water mountain case study, where they arise from the specific geological features of the karstic mountains, the climatic parameters and land use activities.

In the future, problems with water resources are expected to increase due to climate change and rising water demand, for most of the regions analysed in this report. For example, in the Valais, hydrologists expect less glacial melt water to compensate for summer drought, with negative effects on groundwater capacity. The study of Vienna's water mountains concludes that the water availability will change, for example due to an increased number of extreme events, which might cause water turbidity through high rates of mobilised sediments. In Savoy extensive adaptation policies are required to sustain winter tourism in the face of climate change impacts, including measures to diversify the economy.

The Alps are among the areas most affected by climate change in Europe (EEA, 2008a; EC, 2007). On the other hand, the region has high capacity to adapt to the impacts of climate change. The Alps — compared to other mountain areas in Europe — are a relatively rich region with well-defined institutional structures supported by stable states and regulatory frameworks to ensure water distribution among sectors and groups (Wiegandt, 2007). Strong institutions for inter-regional and international cooperation exist including the Alpine Convention, the Platform on Natural Hazards of Alpine Convention (PLANALP), the Commision Internationale pour la Protection des Alpes (CIPRA), the Alliance in the Alps, the Alpine Network of Protected Areas (ALPARC), the Club Arc Alpin (CCA), the Alps-Adriatic Working Community, the Future of the Alpine Rhine Platform, the WWF Alpine Programme, and the International Scientific Committee on Research in the Alps (ISCAR). In contrast to other mountain regions, there are no severe political conflicts between the various alpine regions and countries so that cooperative approaches are relatively easy to achieve.

Due to urgent need for adaptation to climate change in the Alps and the high capacity to realise adaptation in the region one should take this opportunity to implement strategies to adapt to climate change, which would make the Alps a 'pioneer region'. This is in line with the recommendation of the ministerial conference of the Alpine Convention in 2006 (Alpine Convention, 2006), which requested the French presidency of the Alpine Convention to draft an Action Plan on Climate Change aimed at making the Alps an exemplary region for the prevention of and adaptation to climate change.

For this purpose an information platform on the impacts of climate change and adaptation in the Alps could be set up to support alpine regions in their adaptation activities. The Action Plan on Climate Change of the Alpine Convention will be implemented with the support of the Permanent Secretariat of the Convention, which has been requested to install such an Internet platform that contains relevant and current information on climate change in the Alps and includes good practices in mitigation of and adaptation to climate change. The Xth Alpine Conference in Evian (March 2009) decided to install a platform on 'Water management in the Alps' under Austrian-Swiss Co-Presidency. According to its mandate the platform will work until the XIth Conference, and focus especially on carrying out a survey of relevant water management plans in the alpine region, developing recommendations for sustainable and balanced use of hydropower in the alpine area and assessing developments with regard to the need for adaptation to climate change, as well as some additional tasks. An intensive dialogue with the relevant stakeholders is crucial if the design of the information and coordination platforms is to be adapted to the needs of the stakeholders. The institutions for inter-regional and international cooperation listed above should be included in the dialogue to use synergies and avoids conflicts between various adaptation activities in the Alps.

6.2 From reactive water resource management to proactive adaptation to climate change

6.2.1 Experiences from regional case studies

In the case studies, adaptation to water resource issues was mainly reactive, in that is was driven by specific crises or symptoms. In South Tyrol, for example, the 2003 summer drought triggered concerns and action on measures to prevent severe impacts of such an event in the future. In most of the regions studied in the Alps, adaptation to water resource issues seems to be driven by concrete effects and socio-economic impacts rather than climate change scenarios. Some case studies show that the adaptation measures taken after such crises focus only on the specific symptom(s), while others demonstrate a more strategic and integrative planning approach.

As yet, adaptation to climate change plays only a minor role in decision-making on water resource issues in the regions studied. This is probably because firstly, there has been no major problem with water scarcity or water quality due to climate change in the Alps, secondly, there is a lack of sound knowledge of the possible impacts of climate change on water resources at the local and regional level, and lastly there is a lack of management tools that consider climate change. Whereas the phenomena of too much water producing flooding and natural hazards, and too little snow, with its severe consequences for winter tourism, are strongly attributed to climate change and get a lot of attention, potential droughts and water quality problems due to climate change are not priorities in any of the regions studied in this report. In the case studies droughts only became issues on the political agenda when they resulted in forest fires, such as those in Valais after the 2003 heat wave. In most of the regions the awareness of the risks posed by climate change for water availability is growing but no concrete strategies to adapt to these potential impacts have been implemented in any of the regions so far. Surprisingly, there are no comprehensive drought emergency plans for most of the studied regions.

Some sectors, especially those with a long planning horizon, have advanced more than others in their preparation for the impacts of climate change on water availability. For example, interviews in Valais have shown that adaptation considerations and activities are more advanced in hydropower and forestry than in other sectors. Nevertheless, as has been pointed out in most of the case studies, long-term adaptation strategies to climate change are lacking in water resource management.

6.2.2 *Recommendations for long-term, integrated, adaptive water resource management*

Water resource management in the Alps should take climate change scenarios into account as part of a proactive, precautionary, long-term, integrative, participatory and adaptive water resource management approach. More precise regional climate change and climate change impact models need to be developed and disseminated to improve the knowledge base for taking such long-term adaptation decisions. As has been pointed out in several case studies, local decision-makers perceive that the knowledge base of future local and regional impacts of climate change on water availability is not yet sufficient as a basis for taking concrete adaptation actions.

Nevertheless, future impacts of climate change will remain uncertain to some extent even with further refinement of the impact models, because economic, societal and technological developments, and the resulting greenhouse gas emissions and their effects on the climate system, will be continuing sources of uncertainty. Binding long-term international climate protection regimes can reduce the uncertainty caused by uncertain greenhouse gas emissions (Zebisch *et al.*, 2005). Improved regional climate models can reduce insecurities as to the responses of the climate system to some extent. But future results will also show ranges of uncertainty for climate change indices that may span from positive to negative impacts. In addition, some more important impacts of climate change are often less certain. For example, the range of possible precipitation changes, which are extremely important for different sectors, is more uncertain than the expected temperature increases.

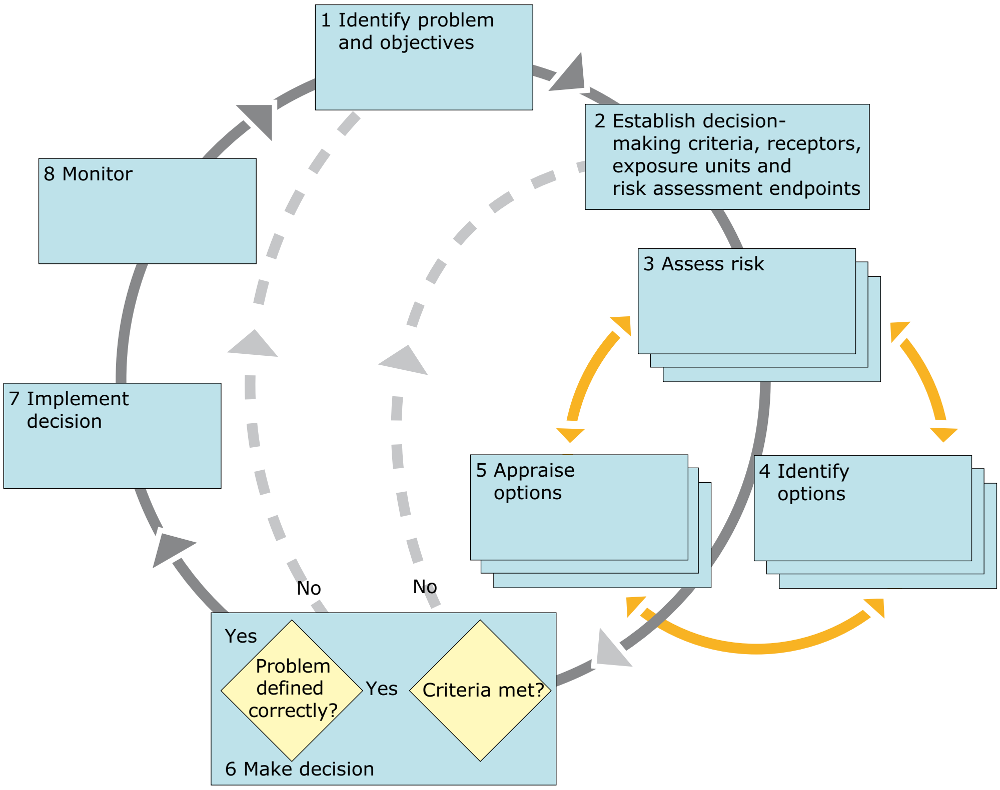
Because of the uncertainties in projections of climate change and its impacts, any adaptation to climate change should be based on the precautionary principle, which is applied to deal with and prevent potential threats when full scientific certainty is lacking (EEA, 2001). Adaptation to climate change, therefore, needs to be seen as decision-making under uncertainty.

There are two main types of uncertainty — informational and normative uncertainty (Newig *et al.*, 2005). Informational uncertainty refers to deficits in knowledge about future climate change and its impacts. Informational uncertainty can only be reduced to a limited extent so adaptation processes should focus on the reduction of normative uncertainty. Normative uncertainty refers to uncertainty about goals and actions and also relates to perceptions of acceptable risk. Normative uncertainty can be reduced to a large extent, especially through participatory decision processes (Pahl-Wostl *et al.*, 2005). For example, strong stakeholder participation in a water-sensitive region can clarify priorities (e.g. on tourism) and acceptable risks (e.g. agricultural losses). Pahl-Wostl *et al.* (2005) developed an adaptive management approach, which incorporates participation at different stages in adaptive water management, starting with (1) participatory policy formulation, through (2) policy implementation, and (3) monitoring and evaluation, and ending with (4) participatory assessment.

More detailed guidelines for adaptation management have been commissioned by the United Kingdom Climate Impact Programme (UKCIP), particularly to tackle the issue of uncertainty in climate change. It describes in eight stages (see Figure 6.1) the entire process from clarification of goals and interests to the choice of adaptation measures, and finally to their implementation and control. The management guidelines follow a flexible and adaptive management approach. A detailed description with specific guiding questions, methods and techniques can be found in Willows and Connel (2003).

Step eight, monitoring, is seen as a particularly important phase of the adaptation process by the authors of several case studies in this report (see also GWP, 2000). The UKCIP adaptation guidelines define monitoring only in terms of the evaluation of the progress, obstacles and effectiveness of the adaptation measures. However, it seems useful to understand adaptation and monitoring as a continuing learning process (Hinkel *et al.*, 2009), in which not only data on adaptation measures but also data and results on water availability, water use, climate change and climate change impacts are systematically collected, analysed and permanently fed into an adaptive adaptation process. This adaptive management approach enables the decision developers to change former decisions and adaptation measures based on new knowledge. On the other side, government

Figure 6.1 Eight-stage concept for decisions on adaptation to climate change



Source: Willows and Connel, 2003.

and business managers need reliable planning for their investments. Therefore, when adjusting former decisions in response to new knowledge, adaptive management often needs to stick to specific time intervals which are economically reasonable.

In addressing the role of knowledge and learning it seems advisable to include deliberative forms of knowledge generation. These involve participatory transdisciplinary forms of learning whereby different bodies of knowledge from science and other societal groups such as business communities or non-governmental organisations bring their knowledge together (van Asselt and Rijkens-Klomp, 2002; Grothmann and Siebenhüner, in press; Kasemir *et al.*, 2003; Siebenhüner, 2004; Voß and Kemp, 2006).

The following key elements of a participatory, precautionary and adaptive adaptation process can be identified from different sources (e.g. Anderson *et al.*, 2008; Kurukulasuriya and Rosenthal, 2003; Lemmen and Warren, 2004; Pahl-Wostl *et al.*, 2005; Willows and Connell, 2003):

- estimation (instead of precise assessments) of a region's or sector's vulnerability to climate change and other pressures and clarification of acceptable risks;
- priority on no-regret, low-regret and win-win adaptation options, which deliver benefits under any foreseeable climate scenario, including present day climate (e.g. increased storage capacities of water reservoirs are advantageous during droughts and flooding ([23]));
- increasing a region's or sector's general adaptive capacity to different potential future climatic and socio-economic developments (e.g. by increasing institutional and management capacities);
- ranking of adaptation options rather than detailed predictions of their costs and benefits;

([23]) However, this strategy might face contradiction with the strict goals of the EU Water Framework Directive prohibiting any aggravation of the ecological status of a river.

- appropriateness of precautionary actions to risks (the higher the potential for damage of the risk the higher the need for precautionary action);
- continuing scientific monitoring and research to learn from adaptation experiences and feed new knowledge into the adaptation process;
- genuine stakeholder and public involvement to reduce normative uncertainty and detect unwanted effects of adaptation measures (as part of the monitoring process);
- flexibility of the adaptation process, so that adaptation decisions and measures can easily be adjusted to new conditions.

In the case studies, adaptation to water resource issues was mainly reactive, driven by specific crises or symptoms. In some cases, the adaptation measures taken after such crises focused merely on the specific symptom(s) and lacked an integrated approach. Therefore, besides adopting the precautionary principle, adaptation to climate change in water resource management should follow the framework of Integrated Water Resource Management (IWRM). The integrative and long-term IWRM framework promotes coordinated development and management of water, land and related resources to maximise economic and social welfare in an equitable manner without compromising ecosystems sustainability (GWP, 2000). It is the overall framework within which all UN Water efforts for addressing water scarcity take place (UN Water, 2006). Given that climate change is usually only one driving force among others like land-use change or economic development (Lemmen and Warren, 2004), the Intergovernmental Panel on Climate Change (IPCC) expects that the IWRM paradigm will be increasingly followed around the world to reduce the vulnerability of freshwater systems (Bates *et al.*, 2008). All the recommendations for adaptation developed in this chapter can be seen as specifications of IWRM in the context of climate change. Through an integral perspective on cross-sectoral water resource uses, the IWRM provides a framework to improve and enhance existing management structures and to increase efficient water uses. Three central criteria guide the IWRM: (1) the economic efficiency of water uses, (2) equity and the right to an adequate supply of good quality water in sufficient quantity, and (3) environmental and ecological sustainability. Measures for adaptation to climate change can thus be analysed within this framework with regard to their effects upon ecological, economic and social objectives. In the IWRM framework complementary elements for the management of the resources have to be developed and strengthened concurrently. These elements include the enabling environment,

Table 6.1 Long- and short-term measures for water resource management

Prevent	Improved resilience	Prepare	Respond	Recover
Reducing need for water Water conservation measures/effective water use (industrial and other sectors' practices and technologies) Water saving (permit systems for water users) Improved irrigation efficiency Land-use management	Enlarging the availability of water (e.g. increase of reservoir capacity) Improving the landscape water balance Introduction or strengthening of a sustainable groundwater management strategy Joint operation of water supply and water management networks or building of new networks Identification and evaluation of alternative strategic water resources (surface and groundwater) Identification and evaluation of alternative technological solutions (reuse of waste water) Increase of storage capacity (for surface and ground waters), both natural and artificial Early warning systems and short-term response plans to avoid situations of severe water scarcity	Prioritisation of water use Restrictions for water abstraction for appointed uses Emergency planning Awareness-raising Risk communication to the public and water sensitive sectors Training and exercise	Emergency medical care Safe drinking water distribution Safe sanitation provision	Rehabilitation plans Insurance solutions for drought damage
↑	↑	↑	↑	↑
		Monitoring and reporting		

Source: Adapted and complemented from UNECE, 2008.

the definition of institutional roles and functions and the use of management instruments (GWP, 2000). The enabling environment comprises the general framework of the policy, legislation and regulations, and information for water resource management stakeholders.

Another highly integrated approach has been developed under the Convention on Biological Diversity (CBD) based on the ecosystem services paradigm (see Chapter 4). This 'strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way' (CBD, 2008a) can be used to align various adaptation activities in addition to the IWRM framework. As operational guidance for implementing the CBD's ecosystem approach it suggests that ecosystem management should involve a learning process which helps to continuously adapt methodologies and practices to approaches that prove to be effective in practice. Similarly, there is a need for flexibility in terms of an adaptive management approach that builds on its results as it progresses. This 'learning by doing' will also serve as an important source of information on how best to monitor the results of management and evaluate whether established goals are being attained. The following five points are proposed as operational guidance in applying the principles of the ecosystem approach:

1 Focus on the relationships and processes within ecosystem.

2 Enhance benefit-sharing.

3 Use adaptive management practices.

4 Carry out management actions at the scale appropriate for the issue being addressed, with decentralisation to lowest appropriate level.

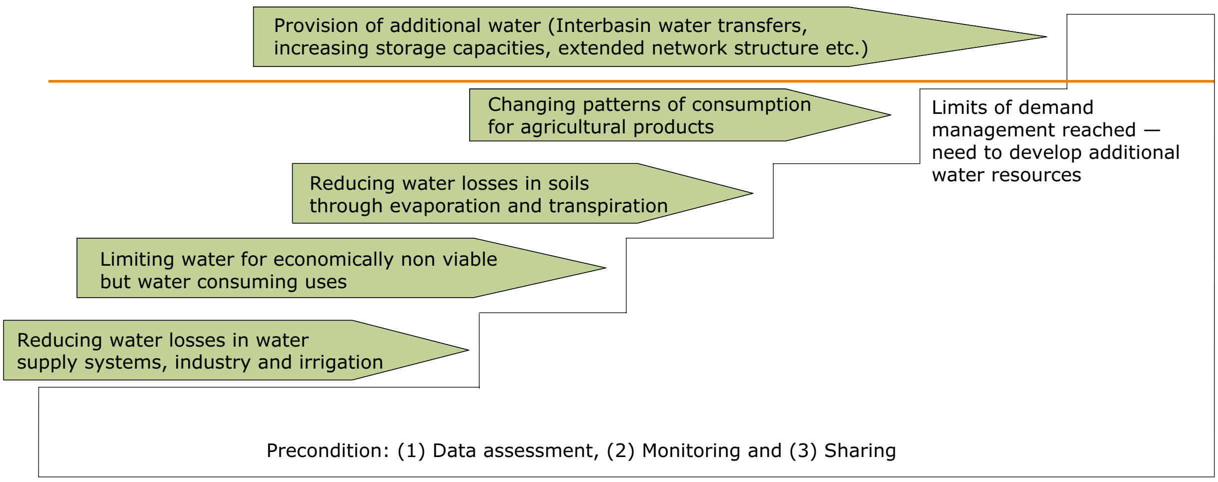
5 Ensure cross-sectoral cooperation.

The management of water should be explicitly included in specifying the ecosystem approach. A detailed Advanced User Guide (CBD, 2008b) has been developed that defines tasks for applying the approach in practice.

It is important to define and provide a legal basis and thus to provide an area for manoeuvre for decision-makers and local stakeholders. The EU Water Framework Directive (WFD), incorporating the basic IWRM criteria, is an important tool for integrated river basin management (see also Chapter 7) and provides one important regulatory basis for adaptation.

Nevertheless, 'climate proofing' — the task of ensuring sufficient consideration of climate change — is just beginning in EU, national, federal, regional and local policies, legislation and regulations for water resource management. Most policies and regulations have not yet been analysed with regard to the challenges posed by climate change. But integration of climate change adaptation into policies at European, national, regional and local levels is a key to a long-term reduction in the vulnerability of ecosystems, economic sectors, landscapes and communities to climate change impacts (EEA, 2008b).

Figure 6.2 Steps to adapt to water resource issues



Source: Adapted and complemented from Falkenmark, 2007.

To substantiate the general recommendation that water resource management in the Alps should follow a long-term water resource management approach, concrete water management measures can be classified as long-term and short-term strategies, measures for prevention as well as measures for times of drought. Table 6.1 gives an overview of measures to prevent, increase resilience against, prepare for, respond to and recover from water shortage, accompanied by a monitoring and reporting scheme to evaluate the efficiency of the implemented measures.

One of the central strategies to prevent water shortages is the gradual expansion of water conservation measures to reduce pressure on the resource (Falkenmark, 2007). This will benefit the various water users and reduce their vulnerability to increasing water shortages and competition for water. Higher water use efficiency becomes even more relevant against a background of climate change mitigation, as less water use results in smaller energy demand for pumping and water treatment. Adaptation to water resource issues should proceed in a timely manner; following a step-by-step approach that should not constrain alternatives through inadequate and too extensive investments (see Figure 6.2). For example, losses from water supply systems should be reduced before restrictions are imposed on economically non-viable water consuming uses. Not only should new measures be addressed in adaptation of water resource management for climate change, but existing water management practices should also undergo climate proofing.

6.3 Complementing technological solutions with behavioural adaptation

6.3.1 *Experiences from regional case studies*

In the case studies, adaptation to water resource issues has mainly followed a technological, supply management approach. For example, the main adaptation activities in Savoy are technological, including inter-basin pipeline transfer and groundwater pumping, construction of new reservoirs for tourism-related water needs and water purification (desulphurisation) to ensure water for local communes. Similarly, water resource management in South Tyrol currently focuses mainly on technological solutions (construction of new reservoirs, improved irrigation and artificial snow-making methods). The same focus applies in the Valais. These technological solutions are very much connected to a supply management approach, which tries to satisfy a demand for water.

Some case studies, however, also show behavioural, demand management measures, which aim at influencing water demand and water use practices. For example, in the Lavant valley activities have been undertaken to raise awareness of water resource issues among the water users, while in the mountain region supplying the water for Vienna, cross-sectoral coordination between different land users has been organised. Not all technological solutions can be assigned to a supply management approach. For example, the promotion of drop irrigation in South Tyrol qualifies as a demand management practice.

As yet, changes in water availability and information about climate change have not led to a fundamental change in water resource management practices in the regions studied. Current water management practices are in line with traditional water management practices. A fundamental structural change, such as the abandonment of winter ski tourism, has not yet been considered in any of the regions studied.

6.3.2 *Recommendations for integrated demand and supply management*

Considering the potential impacts of climate change on water resources and the increasing demand for water in sectors like tourism, it seems advisable that future water resource management should follow a demand and supply management approach, promoting both technological as well as behavioural solutions. Certainly, technological solutions were successful in the past and should also be an integral part of future water resource management. Those technological solutions that aim at reducing water demand seem especially promising. The development of drought-resistant agricultural crops, better water re-use techniques and the expansion of drop irrigation are some examples. Behavioural demand management practices such as water use coordination platforms (to coordinate different water users), public education, targeted education of commercial users or reduction of irrigation through water-efficient landscaping or water restrictions should also be considered.

The need for a fundamental structural change, such as the cessation of winter ski tourism in any of the regions studied cannot be concluded from this report. Nevertheless, this option should not be excluded from future thinking about adaptation to climate change in specific water-sensitive regions of the Alps.

6.4 From sectoral to cross-sectoral adaptation

6.4.1 Experiences from regional case studies

Many of the stakeholders interviewed in the regional case studies presented in this report stressed the importance of cross-sectoral coordination in regional water resource management. Whereas cross-sectoral coordination often seems to work well on the local level (e.g. in Valais) it seems to be lacking at the regional level. In most cases the use of water by different sectors is coordinated through legal obligations. For example, in South Tyrol water is managed cross sectorally by means of a common water use plan and a related system of water concessions. Voluntary and more flexible forms of cross-sectoral coordination could not be identified in the case studies.

As has been pointed out in the South Tyrol case study and in Chapter 4, each sector has its own specific pattern of water availability, water shortage and adaptation measures. In many sectors water use is not distributed evenly over the year. Therefore, in some cases water competition arises at specific periods of the year. For example, water for the energy sector is needed throughout the year with a peak in the winter season due to the heating demand. At least in the Savoy region, hydroelectric reservoirs currently also deliver enough water for snow-making.

At present, water-related conflicts between different sectoral water users are rare. For example, in Valais conflicts between stakeholders hardly ever arise because of a set of accepted traditions, rules and laws, the distribution of responsibilities and existing communication networks, which are not always formally institutionalised. However, increasing water demand in some sectors (e.g. in the tourism sector of South Tyrol due to new hotels, water use for spas and snow-making) and decreasing water availability due to climate change might lead to a growing potential for conflict between different sectoral water users. Conflict between water use for certain sectors and other objectives also has to be expected, as the case of Valais, where many small power plants are planned on running waters, including drinking water pipelines, which potentially conflict with ecosystem protection.

6.4.2 Recommendations for cross-sectoral coordination of water use

The increasing demand for water in some sectors and the risk of decreasing water availability because of climate change might create a need for more and new forms of cross-sectoral cooperation in future water resource management in water-sensitive regions of the Alps. Through its integral perspective on cross-sectoral water resource uses, IWRM provides a framework for the improvement and enhancement of existing management structures and within which to increase efficient use of water. IWRM is the guiding principle of the WFD, which also explicitly addresses cross-sectoral coordination of water use. Although the WFD provides a comprehensive legal framework for the implementation of IWRM, new challenges will emerge with climate change. Furthermore many obstacles still exist to the implementation of river basin management plans and the enforcement of the Programme of Measures. There is no clear legal obligation to implement the Program of Measures, and responsibilities of user groups differ depending on regional law (Durner, 2009). Cross-sectoral coordination is also a key element of the ecosystem services management approach of the Convention on Biological Diversity (CBD).

Coordination platforms for sectoral water users at a regional level seem particularly advisable for mutual understanding of water needs and for identifying and implementing innovative and regionally adjusted water use solutions. The identification of win-win situations for different sectoral users, no-regret and low-regret options can also serve as guiding principles. Such coordination platforms can partly substitute for regulative solutions, which are often less flexible than such cooperative structures — an advantage which fits well with the need for an adaptive management approach to respond to the uncertainty of climate change impacts.

Coordination platforms can also help avoid water conflicts between sectors. Potential conflicts between different sectoral water users have been identified in Chapter 4. In addition, regional mechanisms for conflict resolution are needed to adapt to the rising potential for conflict between different sectoral water users. Moreover, mechanisms for clear priority setting for specific water uses during periods of water scarcity seems advisable to avoid water conflicts and aggravation of water scarcity situations, but are not yet available in most of the regions studied in this report.

6.5 From local to regional and inter-regional adaptation

6.5.1 Experiences from regional case studies

The case studies show that adaptation to water resource issues is organised at the local and regional levels and is also partly embedded in national frameworks. In Valais, coordination of water resources is organised mainly at the local level and water resource management measures are implemented locally with local effects. Water resources are only coordinated at the regional level in the hydropower sector, although there is a trend towards more coordination at the regional level for other sectors. In Savoy there is inter-communal water sharing. The same practice is followed in the Lavant valley where a water supply network connects the different communities. It is, however, expected that additional pressure on water resources through climate change might lead to a negative trend towards uncoordinated reactions and individual communal solutions.

Inter-regional coordination of water resource management was only noted in the case study of the Vienna water mountain. Water management is coordinated in the karstic mountain regions, which play a vital role in the water supply of 2 million people including the city of Vienna. In the other case studies coordination of water resource management with other regions has not yet been necessary, because regional water resources are still sufficient to fulfil the regions' water demands. It seems that water transfer from other regions to the regions included in this report will only become necessary if water availability decreased severely and existing regional water saving options (repair of leaky water pipelines, implementation of drop irrigation, etc.) remained unrealised. Nevertheless, the importance of the Alps as the water towers of Europe will probably increase the need for inter-regional coordination of water use between upstream water users in the Alps and downstream water users along the rivers springing from the Alps (a challenge discussed in Chapter 7).

6.5.2 Recommendations for adaptation on a regional and inter-regional scale

As has already been argued for cross-sectoral coordination of water use, it seems advisable to adapt to climate change impacts (including potentially decreasing water resources) at the regional scale. At present, water resource management is mostly organised at the local (communal and municipal) scale in Europe, although the regions analysed in this report are also examples of water resource management at the regional scale. In the future, the need for inter-communal water transfers and an associated coordination of water use will probably increase. However, local solutions adapted to local conditions and viable with modest communication and cooperation efforts, will remain important components of water resource management into the future.

Adaptation to climate change at a regional scale has further advantages. Compared to adaptation at a federal or national level, regional adaptation strategies allow for a more problem-oriented and stakeholder-specific perspective. Compared to adaptation activities at the local level, regional strategies can include a broader portfolio of potential adaptation decisions. Regions are bound to communal, federal, national, European and international regulations or frameworks. Nevertheless, the regional level of decision-making is not as institutionalised as these other levels so that it seems well suited to the more flexible and adaptive management approach, which seems necessary to deal with the uncertainties of climate change.

There is no general recommendation for the ideal design of regional governance of water resources. Rather, it is important to improve regional governance capacity as a prerequisite for successful climate change adaptation in the water sector. Regional governance capacity refers to a region's capacity to work on issues and solve problems collectively (Le Galès, 1998; Norris, 2001; Pütz, 2004; Savitch and Vogel, 2000). Generally speaking, regions are all the more effective when they are capable of organising collective action and meeting the challenges of inter-regional competition and coordination (Fürst, 2003). Therefore, the key issue in regional adaptation to climate change is to incorporate a multitude of stakeholders from different sectors, different scales and neighbouring regions. The participation of stakeholders is important to integrate knowledge and experience from different fields. Involving stakeholders is also important in order to prevent cross-sectoral and intra-regional conflicts. Therefore, regional water management platforms that integrate relevant stakeholders in the region appear crucial for successful adaptation to climate change and water resource issues.

Measures to improve the regional governance capacity are:

- tackling water resource issues within the perimeters of river basins or catchment areas, not in administrative units;

- establishing of a regional consensus about adaptation goals, strategies and implementation measures;
- agreeing upon mechanisms of conflict prevention and solving;
- establishing regional leadership;
- democratic legitimation of the regional governance scheme;
- embedding regional governance of water resources in integrated water resources management concepts or river basin management plans (see Chapter 7).

In addition, it seems advisable to pursue adaptation at an inter-regional scale in the Alps. For this purpose an information platform on climate change impacts and adaptation options in the Alps should be implemented to support regions in the Alps in their adaptation activities. In addition, existing cooperative platforms and institutions in the alpine area (Alpine Convention, Alliance in the Alps, PLANALP, CIPRA, ALPARC) for further existing institutions should be used to achieve synergies and avoid conflicts between different adaptation activities in the Alps.

6.6 Improving multi-level governance and information flow

6.6.1 Experiences from regional case studies

The case studies showed that there was insufficient coordination of both horizontal coordination problems such as cross-sectoral or inter-regional coordination and vertical coordination between different levels of governance and management (or in other words: multilevel governance). For example, in the Valais case study climate change scenarios produced at the national level did not reach regional decision-makers.

It can be assumed that horizontal coordination problems also exist with regard to inconsistencies in legal regulations at the EU, national or federal levels and in local or regional requirements for adaptation to climate change. Since adaptation to climate change is in its early stages in the regions studied these inconsistencies cannot yet be specified more clearly.

6.6.2 Recommendations for improving multilevel governance

The coordination and integration of different levels of policy-making and management is a challenge not only for adaptation to climate change and water resource management but also for other societal problems. As for cross-sectoral and inter-regional coordination, coordination platforms also seem advisable for vertical integration of various decision levels in order to convey a mutual understanding of the different perspectives on the adaptation problem. The levels (local, regional, federal, national and/or EU) to be included depend on the specific adaptation problem and the specific regulative and socio-economic context.

One important part of such coordination efforts will probably be the climate proofing of EU, national, federal, regional and local policies, legislation and regulations for water resource management.

6.7 Drivers of and barriers to adaptation to water resource issues

6.7.1 Experiences from regional case studies

Many drivers of and barriers to adaptation to water resource issues in the regions studied in this report have already been described: Adaptation was mainly taken reactively, driven by specific water crises or symptoms, mostly following a supply management approach, sometimes hindered by lack of cross-sectoral, inter-regional or vertical coordination. Nevertheless, the case studies differ in their emphasis on specific drivers of adaptation and barriers to it. Whereas the Valais case study highlights that water resource management measures have been primarily motivated by economic reasons or by the task to reduce risks of natural hazards, the South Tyrol case points to the importance of a regulative system (e.g. water concessions) and financial subsidies, which support the introduction of innovative water-saving techniques. The Lavant valley study emphasises, among other factors, the role of governmental activities in terms of providing strategic statewide policies for water supply. It also underlines the role of specific persons, since the foundation of the Lavant valley water association network evolved from the initiative of a single individual who was aware of the local water supply difficulties. The Viennese water case study stresses many different important factors, for example the strong commitment of policy decision-makers to secure water resources, personal contact with the local population and their involvement in the water management process (e.g. as employees), and sound data collection.

A questionnaire was developed to identify the most important barriers to and drivers of adaptation to water resource issues in the various regional case studies. This was based upon the factors identified by the stakeholder workshop (see Chapter 5) to identify lessons learnt from the different case studies, upon the barriers to and drivers of adaptation described in the 3rd and 4th Assessment Reports of the IPCC (Adger *et al.*, 2007; Smit and Pilifosova, 2001), and various publications on water management (e.g. Falkenmark, 2007; GWP, 2000; Newig *et al.*, 2005; Ostrom, 2008; Pahl-Wostl, 2005). Figure 6.3 includes most of the factors (barriers and drivers) incorporated in this questionnaire. The case study author's answers revealed that all the factors named in the questionnaire were relevant in at least one case study, the importance of the various factors differed to a large extent between regions, and the only factor which was identified in all case studies as a very important barrier to adaptation to climate change was the lack of planning and management tools that consider climate change.

6.7.2 Recommendations for analysing and considering barriers and drivers of adaptation

The questionnaire's conclusion that all factors named were relevant in at least one case study indicated that none of the factors should be excluded as irrelevant by anyone wishing to start a process of adaptation to water resource issues and climate change at the regional scale. This recommendation points to the need for integrated management approaches like Integrated Water Resource Management, in which complementary elements for the management of water resources (enabling environment, the definition of institutional roles and functions and the use of management instruments) have to be developed and strengthened concurrently (GWP, 2000).

The questionnaire's outcome that the importance of the various factors for the process of adaptation to water resource issues differed to a large extent between the regions analysed again highlights the importance of careful analysis of regional conditions before and during an adaptation process. The specific situation with regard to potential constraints to and drivers of adaptation should be analysed before a process of adaptation to water resource issues and climate change is initiated in a region with care. During the process of adaptation a monitoring scheme should be set up to detect new barriers and make use of new adaptation drivers. Figure 6.3 can be used as a starting point for such an analysis and monitoring.

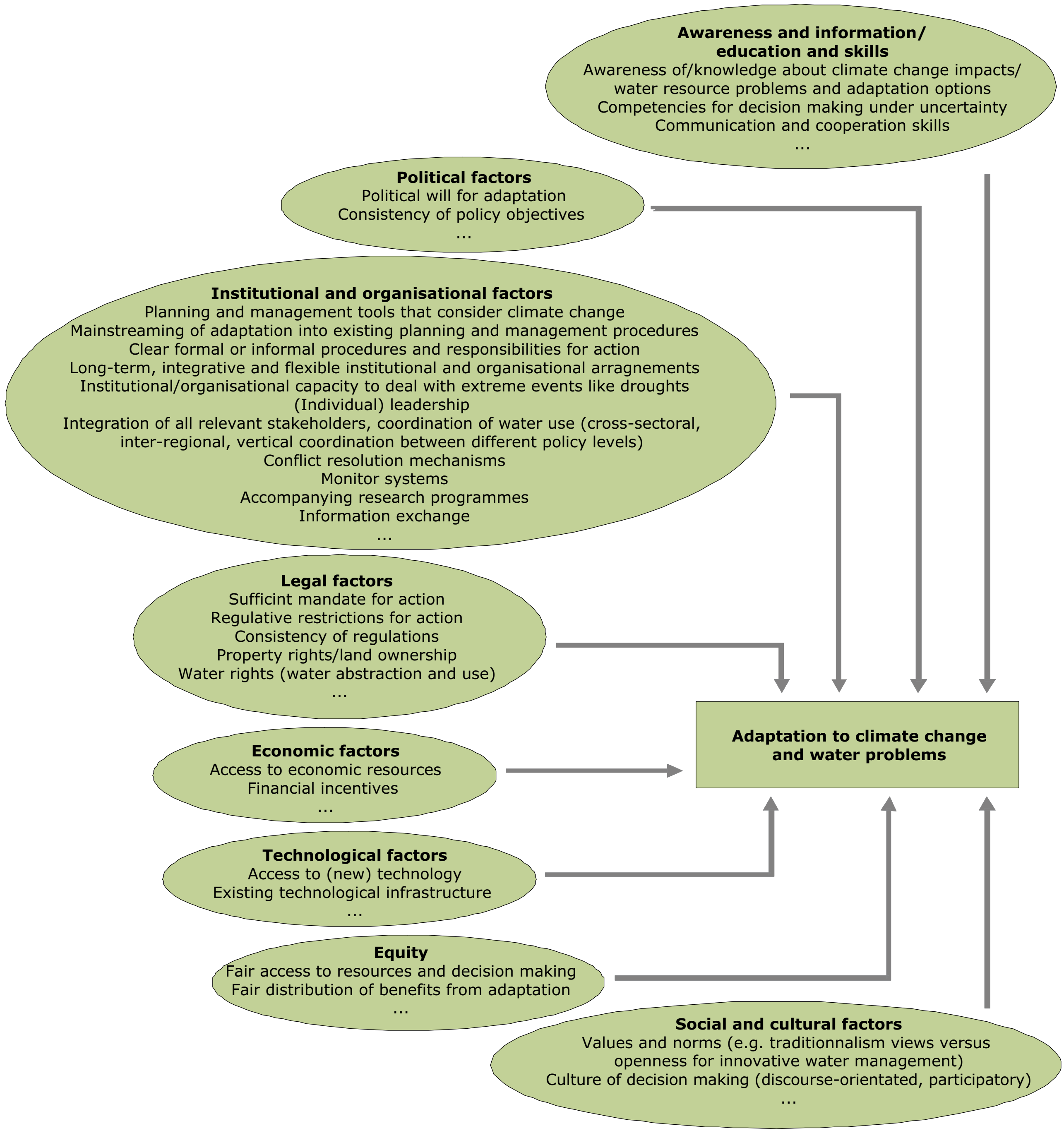
The finding that the only factor which was identified in *all* case studies as a very important barrier to adaptation to climate change was the lack of planning and management tools that consider climate change, shows that, although such management tools exist (for example the eight-stages concept by UKCIP presented above), they do not seem to be known among local and regional decision-makers. Obviously, there is a need to disseminate such management tools more strongly.

Generally, the results of these case studies highlight the importance of social, institutional and management factors in addition to legal, economic and technological factors. This outcome is very much in accordance with results from new studies carried out since the 3rd Assessment Report of the IPCC (Smit and Pilifosova, 2001), which show that adaptation is influenced not only by economic development and technology, but also by social factors such as human capital (education, skills, etc.) and governance structures (Berkhout *et al.*, 2006; Brooks and Adger 2005; Eriksen and Kelly, 2007; Klein and Smith, 2003; Næss *et al.*, 2005; Tompkins, 2005). There are many examples where social capital, social networks, values, perceptions, interests, customs, and traditions affect the capability of communities to adapt to risks related to climate change (Adger *et al.*, 2007). In line with such 'soft' factors it was argued in Chapter 1 that adaptive capacity is determined by institutional and economic capacity but also by the willingness to adapt (EEA, 2008a; Grothmann and Patt, 2005).

Some case studies stress that cost-benefit considerations are important for initiating adaptation. Although this result refers to the importance of economic factors, it also represents the significance of perceptions. The costs and benefits of adaptation can be misperceived. Therefore, communication (through the media and other channels) of realistic costs and benefits of adaptation needs to be structured in such a way that it reaches and is understood by local and regional decision-makers (Zebisch *et al.*, 2005).

Legal requirements (e.g. EU WFD, priority uses), economic incentives (e.g. water prices, water markets), the availability of technological adaptation solutions (e.g. drop irrigation) and especially concrete water resource issues seem to be important as triggers and boundary conditions for adaptation. The adaptation processes themselves seem to depend more on the people involved — their motivation, interests, knowledge, perceptions, competences and the availability of leaders and facilitators — and institutional and organisational factors such as the management of the adaptation process, effective stakeholder participation and the nature of cooperative structures between different sectors, communities, regions and policy levels.

Figure 6.3 Important factors for adaptation to climate change and water resource issues



Source: ETC/ACC, 2009.

7 Adaptation at the European scale — cooperation with alpine water towers

Key messages

This chapter investigates the role of transboundary cooperation on water scarcity and drought issues and explores drivers and triggers for international collaboration in the Rhine and Danube river basins. It specifically addresses the needs and interests of national and European decision-makers facing the challenge of adapting to water scarcity and climate change, especially with regard to transboundary river management. The chapter is partly based upon experiences from the illustrative regional case studies presented in Chapter 5. Most information stems from broader research on water resource management and adaptation to climate change.

In the past, international cooperation was initiated to deal with water quality problems and the control of accidents and spills, while later the issue of floods predominated. The topic of water scarcity and low flow management is an issue for future engagement in most river basins. Research programmes are ongoing but so far there has been limited transboundary cooperation on the issue.

Insights from international cooperation processes together with provisions from the principles of IWRM and adaptive management presented in Chapter 6 form the basis for the following recommendations for international cooperation:

- Transboundary cooperation is relevant to manage and regulate the complex multiple-use systems of river basins and to prevent cumulative negative impacts downstream. Synergies from coordinated transboundary collaboration emerge from the implementation of adaptation measures to diverse problems, such as flood and drought adaptation, allowing robust and cost-efficient solutions.
- To support adaptation processes the regional level should be better informed about and integrated into higher-level decision-making processes. Information and knowledge transfer should be improved across all levels. The role of regions and pilot projects as active nuclei for adaptation process and drivers of inter-regional cooperation should be further considered.
- The coordination of water and land management through the Water Framework Directive (WFD) and the Common Agricultural Policy (CAP) needs to be further streamlined to avoid contrary objectives. Conflicts between mitigation policies in the field of alternative energy production (e.g. Renewable Energy Directive) and adaptation/water policies should also be avoided. Adaptation has to be further integrated in sectoral policies.
- Active participation in decision-making processes and the integration of institutional learning and dissemination of knowledge support adaptive decision-making and increase the capacity of institutions to act autonomously and across regions. Active, integrative actor networks, e.g. River Basin Commissions and other mechanisms for regional cooperation, help to discuss and implement transboundary policies in a traditional setting.
- Innovative financing and compensation mechanisms need to be identified as a trigger for the coordination of upstream — downstream interests, to create a fair distribution of costs and benefits.
- The knowledge base of upstream-downstream climate change impacts needs to be enhanced, and insights assessed and communicated to regional decision-makers. Innovative inter-regional management schemes can be implemented and evaluated on the basis of extensive basin-wide monitoring and joint data collection. This contributes to building trust between the parties and to the identification and resolution of possible conflicts, thus contributing to the creation of a European culture of 'hydrosolidarity'.

Key messages (cont.)

Many lessons learnt from the adaptation experiences in the European Alps are of generic nature and can be considered as guiding examples to support adaptation in other mountain regions. Between regions the importance of barriers to and drivers of adaptation may differ. The following issues appear as important elements to consider for successfully developing adaptation strategies:

- an analysis of the current problems, future risks and the uncertainty due to knowledge deficits, as well as the political and socio-economic framework,
- dialogue between all stakeholders, cooperation and knowledge transfer,
- the use of tools for management under uncertainty, including participative, iterative and monitoring elements,
- cross-sectoral and inter-regional cooperation, and
- the introduction step by step of measures starting with potential win-win options.

7.1 Downstream resource dependencies

The Alps will be more seriously affected by climate change than other regions in Europe (see Chapters 2 and 3), which will also alter its role as a natural 'water tower' for large parts of Europe. This may become precarious for riparian countries sharing water resources along transboundary rivers especially in dry periods.

Upstream and downstream riparian states and regions are intrinsically linked through the joint use of a common resource. Naturally the management and use system of parties upstream directly impact those downstream. Ultimately any change in the natural conditions and uses within the upper river catchment will result in a change of the resource base for water users in regions or countries downstream.

Water resource availability depends on quantitative and qualitative aspects of the hydrological cycle, including the capacity to store water, as well as on the water and land use of the different regions and sectors. Future water availability will be strongly influenced by the varying impact of climate change, which will also significantly influence the lowlands of the Rhine, Rhone, Po and Danube, as was evident in Chapter 3. The Alps are already disproportionately important for the river flow in the riparian countries (Viviroli and Weingartner, 2004). Cumulative negative impacts of climate change will occur in delta regions due to rising sea levels leading to increased intrusion of salt water and salinisation of groundwater resources in coastal areas. This problem will be exacerbated by reduced stream flows. Currently, water resource availability is determined by socio-economic conditions rather than by climate change. In future competition for the resource will increase, due to growing economic development, climate change adaptation (e.g. artificial snow production) and mitigation measures (e.g. expanding CO_2-neutral energy sources, such as hydropower). Chapter 4 identified the impacts of climate change on sectoral developments and the preconditions for competition for water between the sectors. This has also an inter-regional and international dimension because of the transboundary situation of the watercourses originating in the Alps.

Lessons learnt

In times of water shortage, intensive resource utilisation in combination with natural changes in the resources availability due to impacts of climate change may result in temporarily reduced water supply and water quality. These effects may multiply downstream due to the disproportionate importance of the Alps for the river flow volumes. The coordination of basin-wide response measures in periods of low flow and water scarcity is crucial to prevent cumulative negative impacts downstream which may impede economic activities. In particular, energy production, which still depends on large amounts of cooling water withdrawn from streams, will be restricted in times of drought, and some power plants may have to stop production entirely. Therefore, transboundary cooperation on a national scale is relevant to manage and regulate the complex multiple-use systems of river basins. Drought alarm systems should be installed to prepare for extreme situations and provisional arrangements could ensure fulfilment of basic needs for all riparian countries and sharing of economic losses across the basin.

7.2 Cooperation and adaptive management in river basins

The coordination of transboundary river basin management faces different regional problems, differences in legal frameworks, financial and technical capabilities and different cultural and management approaches. The variety of riparian settings needs to be reflected when establishing inter-regional or international cooperation. A suitable guiding framework for this process is the concept of Integrated Water Resource Management (IWRM, see Chapter 6): International and EU legislation, such as the Water Convention and the EU WFD, has adopted the principles of IWRM to promote inter-regional and cross-sectoral resource development.

Without coordination of riparian water management plans and measures, national development objectives may counteract one another, remain inefficient and prevent the achievement of the overall objective of sustainable resource development. Thus, transboundary impacts, including impacts of extreme events such as droughts, should be assessed. In addition to the regional and national process of sectoral coordination, international coordination processes increase the number of relevant stakeholders, which makes river basin management a multi-level, multi stakeholder governance process.

7.2.1 Lessons learnt

It is difficult to assess the extent of any impacts of future climate change both regarding socio-economic developments and water use in the various catchments. The adaptive management principles identified in Chapter 6 should guide transboundary water resource management to prevent detrimental impacts of future water shortage and droughts in the entire basin.

Key elements of precautionary, participatory and adaptive management that have been identified from the literature (e.g. Anderson *et al.*, 2008; Kurukulasuriya and Rosenthal, 2003; Lemmen and Warren, 2004; Pahl-Wostl *et al.*, 2005; Willows and Connell, 2005) are:

- estimation (instead of precise assessments) of vulnerability to climate change and other pressures for the entire basin and for specific sectors, and clarification of acceptable risks;
- priority on no-regret, low-regret and win-win adaptation options, which deliver benefits under any foreseeable climate scenario, including the present day (e.g. improving the water-use efficiency throughout the basin to enlarge the buffer capacity in times of droughts through water conservation measures);
- increasing a region's or sector's general adaptive capacity to different potential future climatic and socio-economic developments (e.g. by increasing the management capacities);
- ranking of adaptation options rather than detailed predictions of their costs and benefits;
- appropriateness of precautionary actions to risks. The higher the damage potential of the risk, the greater the need for taking precautionary action;
- continuing scientific monitoring and research to learn from adaptation experiences and feed new knowledge into the adaptation process;
- genuine stakeholder and public involvement to reduce normative uncertainty and detect unwanted effects of adaptation measures (as part of the monitoring process);
- flexibility of the adaptation process, so that adaptation decisions and measures can easily be adjusted to new conditions (adaptive management).

Apart from reactive responses to climate-related disasters, current research has identified national and international policies as a major driver for proactive adaptation. Other identified drivers were institutional change, land-use change and funding opportunities (Krysanova *et al.*, 2008). In line with this conclusion, the case studies revealed a demand for national policies and tools to trigger and incorporate climate change in the planning process (see Chapter 6). While the regional and local scales are identified as the most appropriate for the implementation of adaptation measures, a lack of knowledge transfer from the top down was revealed. The regional level should be better informed about and integrated into higher-level decision-making processes to better support adaptation processes. Transfer of information and knowledge should be improved across all levels. Thus, a balanced approach between bottom-up and top-down coordination is needed.

To conclude, the capacity of a river basin to adjust and adapt to future climate change is influenced by the capacity of the different regions /states involved to interact with one another, their ability to implement the basic principles of IWRM, and to coordinate and communicate in a multilevel, multi-stakeholder situation in a flexible, adaptive manner. Thus it is recommended that an appropriate platform be found to link all stakeholders to discuss and harmonise policy objectives and strategies across the river basin and to ensure the capacity to act in case of extreme water situations like droughts. The decision of the Xth Alpine Conference in Evian (March 2009) to install a platform 'Water management in the Alps' is an important step in this direction.

7.3 The legal framework for adaptive transboundary river management

Although adaptation to climate change is not yet an explicit obligation in water resource management, provisions for the adaptive management of water and transboundary coordination are given in EU legislation. Moreover, adaptation activities in water resource management are supported by the EU White Paper on Adaptation (EC, 2009) and currently developed national adaptation strategies (EEA, 2008; PEER, 2009). The legal basis for transboundary cooperation is provided through the Water Convention and particularly through the EU Water Framework Directive (WFD). Public participation is recognised by all mentioned directives and conventions as a key mechanism for the implementation process and is anchored in the Aarhus Convention. The proactive approach needed to prevent negative impacts of climate change, where timing and extent of extreme events can hardly be predicted, relies on the precautionary principle. The EC underlines the importance of this principle with reference to climate change. Recommendations for the application of the principle are given in a communication (EC, 2000a).

Relevant policies and their provisions for participatory, precautionary and adaptive water and river basin management are introduced in the following. National and provincial/local water management legislation could not be analysed in this study.

Water Convention: The 1992 Convention on the Protection and Use of Transboundary Watercourses and Lakes (UNECE Water Convention) entered into force in 1996 and provides a legal framework for regional cooperation on shared water resources. Many bilateral and multilateral agreements between European countries are based on its principles and provisions (UNECE, 1992). Currently a guidance paper is being developed under the Protocol on Water and Health to assist governments in developing strategies for adaptation to climate change in the water sector (UNECE, 2008).

EU WFD: The EU Water Framework Directive (2000/60/E) demands an integrated management of transboundary river basins and coordination of management programmes and measures in River Basin Management Plans (RBMP, Article 3). It includes principles of IWRM, and propositions such as viable water pricing shift the focus from the supply side to demand management. The obligation to assess environmental pressures on the basins implies inclusion of climate change impacts (ENECE, 2008). There are several elements of the directive that encourage adaptive management. Most importantly, the repetitive management cycle for the review of RBMP allows continuous assessment and adaptation of management decisions. Requirements for monitoring and information exchange are an important base for assessing impacts and the effectiveness of programme measures and thus support the adaptive process (Henriksen, in press). Although generally not designed to tackle quantitative issues, provisions are included to deal with drought effects and to implement drought management sub-plans if necessary (EC, 2006). Currently, discussions on Climate Change and Water are under way between European water directors as part of the Common Implementation Strategy, which consider the performance of a climate check (EC, 2008a).

EU Water scarcity and drought management: The European Commission's Communication 'Addressing the Challenge of Water Scarcity and Droughts in the European Union' to the Council and European Parliament (EC, 2007a), promotes assessment reports, drought management plans and recommendations of specific prevention and mitigation measures. Numerous participative approaches have taken place at local and river-basin scales to discuss drought impacts, as well as national awareness campaigns to promote water saving (EWP, 2008). An expert network was established by the European Community to provide information about specific problems, such as water scarcity and droughts, and a report on drought management plans in the framework of the Common Implementation Strategy of the WFD, was endorsed by the Water Directors of the Member States in November 2007 (EC, 2008b).

EU Flood Directive (2007/60/EC): The directive requires Member States to assess the risk of flooding for all watercourses and coastlines, to map the extent of likely flooding and the assets and population at risk in these areas, and to take adequate and coordinated measures to reduce this flood risk. The directive should be carried out in coordination with the WFD, with flood risk management plans and river basin management plans (EC, 2007b).

EU Green Paper on Adaptation: The 2007 Green Paper examines the impacts of climate change effects in several European regions and attempts to define the possible adaptation actions which have a pan-European dimension, while recognising that cooperation with and between Member States and regions will be essential. Furthermore, the impacts of droughts and possible adaptation strategies have been investigated (EC, 2007c).

EU White Paper on Adaptation: The 2009 White paper sets out a framework to reduce the EU's vulnerability to the impact of climate change, building on the consultation of the Green Paper. It recognises the water sector as one of the key EU policy sectors, where early action on adaptation is essential. The four pillars of action call for 'building a solid knowledge base on the impact and consequences of climate change for the EU, integrating adaptation into EU key policy areas, employing a combination of policy instruments to ensure effective delivery of adaptation, and stepping up international cooperation on adaptation' (EC, 2009).

Aarhus Convention: The basis for developing and implementing national and transboundary environmental instruments, including those related to adaptation to climate change, is provided in the Aarhus Convention, which is taken up by the EC Liability Directive (EC, 2006b). The Convention imposes obligations on parties and public authorities and grants the public rights regarding access to information, public participation and access to justice.

The European Commission's communication on the precautionary principle: The EC communication provides guidance on the application of the precautionary principle. In the treaty, the principle is only prescribed towards the protection of the environment. However, a broader application to potentially dangerous effects on the environment or on human, animal or plant health is consistent with the high level of protection desired by the Community. A structured approach for a 3-step risk management is recommended, comprising the assessment, management and communication of risks. Scientific evaluation is the start for the implementation of this approach. Any actions should then be proportionate, non-discriminatory, consistent, based on an examination of the potential costs and benefits of action or inaction, subject to scientific review and capable of assigning responsibility for producing the scientific evidence (EC, 2000a). The Rio Declaration provides a definition of the precautionary principle.

Other EU policies: There are other EU policies which will influence the implementation and outcome of the basin-wide management, such as the Common Agricultural Policy (CAP). The CAP has a significant impact on land management patterns influencing water quality. The cross-compliance principle of the CAP includes environmental objectives and thus would need to reflect climate change impacts as well.

Moreover, with the implementation of the Renewable Energy Directive the production of renewable energy such as hydropower, biomass production, solar energy and others will be increased. This energy sources rely on the availability of water resources and at the same time the pressure on water resources from quantitative but also qualitative perspectives may increase, too.

Water management objectives have been formulated within the framework of the Alpine Convention (Article 2.2a) and are an important topic within the protocols for tourism and energy. The Xth Alpine Conference in Evian (March 2009) decided to install a platform 'Water management in the Alps' under Austrian-Swiss Co-Presidency. The Platform will work until the XIth Conference according the decided mandate with special focus on a survey of the relevant water management plans in the alpine region, developing recommendations for sustainable and balanced use of hydropower in the alpine area and assessing the developments with regard to the need for adaptation to climate change as well as some additional tasks. In addition, the ministerial conference of the Alpine Convention in 2006 (Alpine Convention, 2006) asked the French presidency of the Alpine Convention to draft an Action Plan on Climate Change aimed at making the Alps an exemplary region in the prevention of and adaptation to climate change. The Action Plan will be implemented with the support of the Permanent Secretariat of the Convention, which is asked to install an Internet platform with relevant and current information on climate change in the Alps including good practices in mitigation and adaptation to climate change.

Other relevant regulations emerging from transboundary cooperation in the frame of conventions as for the Rhine and Danube will be addressed in the following chapter.

7.3.1 Lessons learnt

So far, no transboundary prevention or risk management strategy exists to deal with water scarcity and droughts in river basins fed by the Alps. A drought mitigation strategy for the Italian part of the basin exists only for the Po. The definition and implications of the precautionary principle need to be discussed in the context of basin-wide water management especially. Experiences from the case studies revealed contrary definitions and differing implications of policies for climate change mitigation and adaptation. For instance, the role of small-scale hydropower plants is considered of great importance in Switzerland, while German environmental policy assessed them as detrimental.

Synergies from coordinated transboundary collaboration in adaptation policies addressing diverse problems may complement each other, and some measures such as increased water retention capacity of the soil, may apply for flood and drought adaptation. This presents a robust and cost-efficient solution and a way to deal with uncertainties. Moreover, EU policies and subsidies should be aligned; and the coordination of water and land management through WFD, CAP and Rural Development Policies, in particular, should ensure complementary objectives.

Conflicts between mitigation policies in the field of alternative energy production (Renewable Energy Directive) and water policies (WFD) should be avoided (see Chapter 4). Adaptive management of both, energy and water need to be explored to ensure energy and water security in the face of climate change.

7.4 Transboundary case studies

International cooperation has a long tradition and stable institutional setting in some basins, and stakeholder networks exist to take up new issues such as adaptation to climate change. Lessons can be drawn from the development of International River Basin Commissions (IRBC) for transboundary cooperation and its implementation. International Commissions exist for the Rivers Rhine and Danube; there is a basin authority for the Po, while a commission for the Rhone is in place only for the sub-basin of Lake Léman. These existing institutions are useful settings to coordinate and support the implementation of EU directives and harmonise national policy objectives. However, they have no authority to directly administer laws, such as the EU WFD (EC, 2008c). Such power remains with the national authorities and the implementation of measures takes place largely at national and regional levels. Other forms of inter-regional cooperation have emerged separately from the international cooperation process, e.g. along the Rhine, representing an action-oriented level. Governance structures and processes along the Rhine and Danube are more closely examined in the following.

7.4.1 The Rhine

In the past, the main triggers for international transboundary cooperation and the management of water resources have been problems with water quality caused by accidents and spills. In the case of the Rhine, cooperation resulted in the establishment of the International Commission for the Protection of the Rhine (ICPR), which consists of high-ranking officials from the national and regional water management authorities of the member states and individual representatives of national planning authorities. Cooperation was pushed forward by the Dutch government due to their concern about deteriorating water quality caused by upstream pollution. The implementation of prevention measures in France could only be gained through means of side payments by the Dutch. The realisation and ratification of a treaty itself was postponed (Dieperink, 2000). Later on, the task of the ICPR extended to the coordination of voluntary flood protection measures including technical, spatial planning and informational elements. In response to widespread flooding in 1992 and 1995, the parties agreed on the International Action Plan (ICPR, 2005). The Convention on the Protection of the Rhine has been in force since 2003, whereby the riparian nations of the Rhine formally confirmed their determination to reinforce their cooperation for the continued protection of the Rhine (EC, 2000). Today, the EU WFD and its daughter directives have become important tools for the implementation of the Rhine Action Programme 'Rhine 2020' (ICPR, 2007) The impact of climate change on water resources and dependent economic sectors is recognised by the ICPR, which demands adaptation measures in all water-dependent sectors. Current research on discharge and low-flow scenarios will provide the basis for the development of policy programmes.

Aside from this international cooperation, activities on the regional level developed simultaneously. An inter-regional coalition within Germany, the 'Hochwassernotgemeinschaft Rhein e.V.' (Rhine Flood Emergency Community), formed in response to the Rhine flood of 1988 (HWNG, 2002). Communities along the middle and lower Rhine formed an alliance to coordinate interests. They aimed to improve their situation through negotiations about water-retention measures with communities upstream (HWNG, 2002). Here again, the interests of the downstream communities could only be implemented by means of side payments (financial contributions). However, the influence of this coalition on the inter-regional planning processes remains rather small (Haupter, 2005).

Cooperation at a transboundary inter-regional level has also emerged in response to flooding experiences. In 1997, a Dutch-German flood working group involving the regions of Westphalia in Germany and Gelderland in the Netherlands was set up for information exchange, joint decision-making and risk assessment. The voluntary, informal process aims to extend its range through the accession of other regions in the Rhine catchment. Another example of inter-regional cooperation is found on the upper Rhine. The regional alliance between German and Swiss communities cooperates on various topics, from natural resource development (groundwater, nature conservation) to economic development. Since the establishment of the Hochrheinkommission a policy-making instrument is available to coordinate transboundary regional and cross-sectoral development.

7.4.2 The Danube

Transboundary cooperation along the Danube has a long tradition dating back into the 19th century. However, it was only in the mid-1980s that quality problems triggered concrete actions to improve the state of the river. At that time the riparian states of the Danube signed the Bucharest declaration to coordinate the joint management of the river, which resulted in a convention nine years later. The implementation of the 1994 Danube River Protection Convention is carried out through the Environmental Programme and is guided by a Strategic Action Plan (SAP), which has exponentially increased the level of international cooperation. The SAP addresses authorities at the national, regional, and local levels, while relevant Regional Environmental Programmes and industry, agriculture and citizen-based organisations all play a role in the implementation of the convention. Joint monitoring networks and exchange of information through National Reviews have been the basis for all ongoing activities in the basin, such as the joint identification of priority issues and risks to ensure cost-efficient investment decisions. Donor organisations helped to implement the action plan. The most distinct feature and factor for success is the broad and active participation process including the public and NGOs throughout the planning process, which helps to preclude future conflicts within countries and internationally. Moreover, a new dimension of the Programme was the promotion of a mix of actions in the public and private sector (Wolf and Newton, 2008). The Framework aimed to support the transition from central management to a decentralised and balanced strategy of regulation and market-based incentives.

7.4.3 Lessons learnt

Both cases are examples of successful transboundary cooperation which is the basis for the implementation of a joint adaptation strategy. Triggers of and barriers to the cooperation process are discussed in the following.

- Experience shows that River Commissions are useful platforms to address and discuss transboundary problems.
- There is a discrepancy between the level of transboundary negotiations and agreements, which mainly involve national representatives, and the levels of the agreements' implementation, which mainly takes place on local and regional levels. It seems advisable to involve local and regional stakeholders more strongly in transboundary negotiations to avoid implementation problems.
- While the topics of concern have changed over the time (from navigation, to quality, accidents and flood issues) there has been a continued engagement between the parties which increased in intensity step by step and supported the development of trust amongst them. This was also an important precondition for the implementation of such an ambitious programme as the Danube Environmental Programme.
- Exchange of information through the national reviews and joint monitoring has been a precondition for the joint identification of priority issues and risks in the basin and cost-efficient investment decisions, but also in identifying and precluding future conflicts and simultaneously supporting trust between the parties.
- Experiences for the Rhine show that a window of opportunity is often needed to succeed with policy objectives, such as in the case of the Netherlands, where awareness on a certain issue, here water pollution, is high and it becomes a politically sensitive topic.
- Another trigger is the active leadership role people or organisations take on to advance the

solution of a certain problem, as in the case of the inter-regional cooperation presented above. Moreover, regions and communities are the level at which adaptation measures are implemented, thus they can be regarded as active nuclei for adaptation processes.

- The Rhine Commission has played an important role in advancing cooperation and joint management, but the implementation of measures depends on the national and regional authorities. Here, the comprehensive approach of the Danube participation process, where all levels relevant for the implementation of measures are addressed, serves as a good example and underlines the importance of broad and active participation of stakeholders from across all levels in platforms such as the River Basin Commissions.

- In the case of the two cooperative activities for the Rhine, the willingness to cooperate and the actual implementation of measures relied on the willingness of downstream beneficiaries to provide side payments through financial contributions to the upstream parties. For the implementation of the Danube Programme donors have been crucial, keeping in mind the unbalanced economic capabilities of the parties. Innovative financing and compensation mechanisms need to be identified as triggers for the coordination of upstream — downstream interests to create a fair distribution of costs and benefits.

- Factors contributing to the progress in the cooperation process on the SAP for the Danube have been joint monitoring and information exchange, the intensive participation process and collaborative problem solving.

- Furthermore, a detailed strategy and assignment of tasks and objectives for each level, with time horizons for the realisation of short- and long-term issues and the implementation of pilot projects at the sub-basin scale can enforce and control progress in the implementation process and are crucial for the success of the programme.

7.5 Recommendations for adaptation in transboundary settings

The implementation of adaptive river basin management relies on a broad approach using regulations, technologies, financial mechanisms and voluntary and communicative persuasive strategies (see Chapter 6). The integration of different elements in the implementation of transboundary river basin management is important for the effectiveness of programmes and measures. Recommendations are based on the insights developed in this chapter and the barriers and drivers identified in Chapter 6.

7.5.1 Coordination and integration of legal frameworks

The existing legal framework provides guidance for the implementation of adaptation measures in national policies. The WFD supports the alignment of measures in international river basins. Sustainable land management (see Chapter 4) is of major importance to enhance the resilience of river basins to climate change impacts, thus policy affecting land and water management has to be developed in harmony. It is important to improve the coordination and development of policies for different sectors to avoid contradictory objectives and subsidies.

Synergies can be obtained through the coordination of policies. They can support cost-efficient and robust solutions. The implementation of the EU Flood Directive and the EU Drought Strategy are good examples of measures with multi-purpose objectives, such as increased retention capacity. Moreover, promotion of water consumption subsidies in the agricultural sector via the Common Agricultural Policy (CAP) needs to be coordinated with the EU WFD.

The definition of basin-wide priority uses may become necessary for times of drought and the development objectives and water needs of water-dependent sectors such as agriculture, thermal and hydropower, tourism, navigation etc., need to be regulated. The issue of basin-wide economic development objectives could be coordinated at the international level for efficient resource use in times of drought and water scarcity. This would be a step toward the prevention of conflict.

7.5.2 Adaptive elements in institutional organisation

Joint data collection across national or regional boundaries is an important precondition for collaborative decision-making to align strategies for adaptation to changes in water availability. Transboundary monitoring networks could be established for this, although the type of data collection would need to be coordinated. Ongoing activities for flood prevention and transboundary flood alarm systems could be complemented by drought alert systems to ensure that precautionary measures are taken early.

Basin-wide development scenarios and projections of water resource availability under assumed paths of economic development are useful tools to identify potential future conflicts within the basin and to support joint decision-making. As shown in the case studies, knowledge transfer from the national to the regional level is often disconnected and needs to be improved to initiate regional adaptation processes.

Facilitating adaptation activities will be most cost-efficient and sustainable if management focuses on precautionary and preventative activities at an early stage. Top-down regulations have been identified as an important trigger for adaptation measures but they are generally the result of a lengthy decision-making process. Inter-regional cooperation can act faster and in informal ways, when it has the authority to implement measures. However, their influence on international negotiations and planning processes is often limited. The participation of regional decision-makers/stakeholders in international institutions such as the ICPR is crucial, as this type of platform supports the facilitation of inter-regional cooperation processes. Cooperation between upstream and downstream stakeholders on a regional scale, such as the regional cooperation along the Rhine, supports trust building between the parties. Regional stakeholder initiatives can help adaptation measures to progress in an active manner. Moreover, as recommended in Chapter 6, it would be useful to have an exchange between regional water management platforms at river basin level.

7.5.3 Knowledge transfer and production

Information sharing and communication is central to deal with uncertainty in decision-making. Strong cooperation between policy makers, scientists and the public should be reached through intensive participatory decision development throughout the basin, as has been important to the cooperation process along the Soča River (see Section 5.7). In the Danube example, intensive participation was an important driver for progress and agreement on developed plans. Provisions by the EU WFD are limited to access to information and planning documents and the chance to comment on these, but no intensive participation is foreseen to actively integrate stakeholders and the public in the decision making process, despite the acknowledgement of its relevance for transparent and informed decision making. Active participation in the definition of objectives may identify synergies between sectors and regions and could also reveal existing or future injustices and conflicts that can then be addressed.

New approaches in information dissemination and learning, such as scenario games and citizen juries, should be adopted to increase institutional and social capacities, increase awareness of climate change impacts and help foster proactive engagement. Social learning in river basin management is a key driver for adaptation processes, sustaining and developing the capacities of all involved stakeholders to experiment, learn, discuss and manage their rivers effectively (Raadgever and Mostert, 2005; Raadgever *et al.*, 2008). Therefore programmes to train the trainers, pilot basins, and collection of best practices within a basin may serve as nuclei for further adaptation and innovation processes.

The planned European clearing house on climate change impacts and adaptation will also play a major role in providing information on transboundary water management in the future by facilitating access to European climate change data/scenarios,
actions/good practice, including costs (EEA, 2008).

7.5.4 Transboundary financing solutions

Funding opportunities and financial incentives have been identified as triggers for adaptation in the regional case studies and for cooperative actions in the river basins studied. Along the course of a river, measures in the upper part of the basin naturally have an impact downstream. Cross-border assessments of costs and benefits can assist in the implementation of measures defined in the RBMP.

Innovative solutions linking upstream — downstream stakeholders could be developed, such as compensation schemes providing funds, side payments, and adaptation of spatial planning. In case of the regional cooperative organisations along the Rhine, adaptation measures upstream were triggered by side payments by the downstream communities who were the beneficiaries of these measures. Such payments can relate to long-term strategies for adaptation, such as changes of land management practices and the improvement of ecosystem services upstream (see Chapter 4). They can also relate to short-term strategies such as technical regulation through upstream dams and reservoirs to ensure a minimum water supply in times of water shortage. The costs for operation or construction of infrastructure could be shared. The implementation of such arrangements depends on an integrated monitoring and decision support system.

Decisions on investments in technology for dams, reservoirs and water supply networks should include broader considerations of their benefits for other stakeholders across regions and for downstream communities to create win-win situations.

7.5.5 *Technology*

Infrastructure projects for water-related problems such as floods should take into account their contribution to managing drought and water scarcity in an inter-regional context. Their operation can thus be adapted to store water resources and prevent floods in periods of abundance, and also to regulate times of low flow.

Infrastructure integration and regional integration are essential to the capacity to act flexibly and should be considered in new infrastructure projects. The identification of impacts and benefits for the larger region and its stakeholders is a necessary step in this process.

New technologies for monitoring and controlling impacts of measures on the various spatial scales need to be developed and implemented to evaluate the effectiveness of projects and programmes and ensure compliance. Moreover, they are the basis for innovative financing tools such as payments for ecosystem services.

Climate change and water in the Pyrenees

The Pyrenees form a natural border between northern and southern Europe. As the region's climate is varied (Mediterranean, continental, oceanic and mountainous), it shelters a rich and varied biodiversity (comprising some 3 500 plants, 75 animal species and 300 avifauna species). It is also 'an ecological niche' for 150 to 200 endemic plants (present only in the Pyrenees) and some animal species such as the Pyrenean Chamois (*Rupicapra pyrenaica*), the Woodgrouse (*Tetrao Urogallus*) or the Bearded Vulture (*Gypaetus Barbatus*). Climate change is amplified in zones where climatic conditions are most extreme, meaning that the Pyrenees face a particularly severe threat.

Climate change impacts
Among the first evidence of global warming's impact is the melting of glaciers. In the Pyrenees the process is far more advanced than in the Alps, with 80 % the surface area having disappeared since 1850 compared to 40 % in alpine regions.

As several studies report, climate change also affects forests by encouraging a shift to higher, cooler altitudes. Penuelas and Boada (2003) report that a 1 °C increase in annual average temperatures in southern Europe causes beech trees in Catalonia to shift uphill by 70 metres over 50 years. A similar uphill shift has been registered in France according to recent studies on the Pyrenees (INRA BIOGECO) and on all French mountains (AgroParisTech).

Other indicators, relating to matters such as snow coverage and agriculture, provide further evidence that climate change is already having a visible impact.

Water issues
The Pyrenees are the water towers for south-west France and northern Spain. Current events in Catalonia already show the difficulties that large cities may encounter. The Mediterranean climate, particularly dry and warm in spring, may aggravate the situation, notably if its area of influence widens to south-west Europe; Toulouse could have similar climatic conditions to Barcelona or Cordoba in coming decades. Studies in Spain highlight the urgent need to address water problems in the Pyrenees, particularly in Catalonia.

On the French side, the limited good quality data are insufficient to identify clear trends but suggest a slight decrease in the flow of some streams and in precipitation. Furthermore, precipitation in the Pyrenees and in the Pyrenean Piedmont could start to exhibit a Mediterranean pattern, i.e. an increase in diluvian rain (intense rainfall, with torrential character).

7.6 Lessons learnt for other mountain regions in Europe

Mountains are especially vulnerable to climate change. Climate change is modifying the hydrological cycle of mountain regions, thus changing water availability in elevated and surrounding regions. A decline in snow and glacier cover is already being observed in most European mountain regions, which could be attributed to warming (EEA, 2008). The impacts of climate change vary between and also inside the different mountain regions depending on such factors as the climate regime, differences in altitude and the landscape units. However, mountain regions which already suffer under natural hazards, from low summer water availability or depend on glacial melt water or winter snow cover are most vulnerable to climate change.

Photo: © European Environment Agency

Mountain regions not only show different biogeographic conditions, but are also influenced by different political and socio-economic circumstances, which determine their adaptive capacity. Climate change can trigger conflicts of interest between environmental sustainability and economic development (EEA, 2005).

Cooperation networks at local to international levels, e.g. the Alpine Convention, the Carpathian Convention or Mountain Partnerships, can assist in adapting to climate change by collaboration in areas such as exchange of information and experience or the development of common projects. A possible link and starting point for cooperation between the Alps and the Carpathians could be Article 6 of the Carpathian Convention (adopted on 22 May 2003) where sustainable and integrated water/river basin management is highlighted. Taking into account the hydrological, biological, ecological and other specificities of mountain river basins, the Parties were requested to take appropriate measures to promote policies supporting the sustainable use of water resources, such as developing and applying integrated river basin management practices. The Parties agreed to ensure an adequate supply of good quality surface and groundwater as well as conserving and protecting natural watercourses, springs, lakes, groundwater and wetland ecosystems.

A further requirement was that they further develop a coordinated or joint system of measures, activities and early warning for transboundary impacts on the water regime, such as climate change.

International frameworks and inter-mountain cooperation become even more important when different mountain regions contribute water to the same river, e.g. part of the Alps and the Carpathians contribute to the Danube. Thus, in 1994, eleven countries and the European Commission signed the Danube River Protection Convention for sustainable and equitable management of the river basin. The Water Framework Directive also requires that management measures in the whole catchment are coordinated in the form of River Basin Management Plans (RBMP). According to the implementation strategy of the European water directors (2008) impacts of climate change will also have to be considered in the RBMPs. Mountain regions outside the EU or transboundary mountain regions which are partly outside the EU, deserve their own regulations based on international law or cooperation agreements similar to the existing international frameworks for river basin management. Existing or new regulations, strategies and agreements have to be made climate proof, i.e. to integrate climate change as a pressure factor and describe options for responding to it, in order to assess risks and challenges for water management arising from climate change impacts.

Many of the adaptation measures described in this report, as well as the experiences gained and recommendations extracted, are of generic nature. The focus is on adaptation strategies and the adaptation process, especially adaptation management, rather than on the specific biogeographic conditions of the Alps. The adaptation process is influenced by local to international frameworks. Generally, social, institutional and management factors, in addition to legal, economic and technological factors are important as drivers for and barriers to the adaptation process. The elements, factors and

UNEP statement on water resources in the Carpathians

The Carpathians are Europe's largest mountain area representing a unique ecosystem with impressive biodiversity where the headwaters of several major rivers originate.

The preliminary study on 'Water resources and natural disasters (climate change) and flood risk mapping' of the EU INTERREG Carpathian project indicates three main areas of importance for water management:

Firstly, water use, summarises the man-made impacts affecting water quality and quantity as well as reduction of biodiversity in certain parts of the Carpathian region. The reasons for these problems lie in pollution (e.g. nutrients, heavy metals, other organic pollutants, etc.) mainly caused by inadequately treated waste water, diffuse pollution by agriculture and industrial accidents and floods. Water quantity is affected by the over exploitation of surface and groundwater resources and man-made changes in river-flow patterns. The degradation and loss of wetlands contributed significantly to a degradation of aquatic ecosystems.

Secondly, droughts and flood hazards are both expected to become more extreme according to predictions of the impacts of climate change. Beside human-induced global warming and associated changing rainfall regimes, hazards are exacerbated by land-use changes (e.g. deforestation) and land movement. The impacts of these hazards have become stronger — floods, especially, take lives and cause enormous economic damage. The economic impact of droughts has also increased significantly. As well as mitigation of catastrophic damage by structural means, non-structural means are increasingly being implemented and participation processes are encouraged by various entities in flood prevention and preparation.

Thirdly legal transposition of EU policy through the European Water Framework Directive is especially relevant, with its objective of reaching a good status for all waters by 2015. This objective is supposed to be met through integrated management at a river-basin scale and the institution of basin authorities and management plans. As non-EU countries of the Carpathians Serbia and Ukraine have their own legal provisions for water management that are not fully focused on a river basin approach. Ukraine intensively cooperates in international projects in this field.

From its beginning, the Carpathian Convention process established strong links with the Alpine Convention, which from 1991 has served as an archetype for the establishment of policy structures for sustainable development in mountain areas. Experience from the Alps and examples in the Carpathians demonstrate that mountains can offer considerable development potential, respecting the value of natural and cultural heritage.

In view of the importance of the Carpathian Mountains to the overall European water balance, follow-up research focusing on this mountain range is highly recommended, building upon the experience and outcomes of the Cadses Carpathian Project.

rules of this process, the cooperation between stakeholders from the private and public sector, and the use of synergies between adaptation and other priorities are of interest for other regions too. Adaptation activities can be distinguished as technological or behavioural and reactive or proactive with different spatial scales (local to international implementation) and integration (sectoral/cross-sectoral), and as singular or embedded in a political-socio-economic framework.

In Chapter 6, recommendations are made for adaptation to future climate change in water-sensitive regions of the European Alps. Most of them are also valid for other mountain regions. Chapter 7 makes recommendations for transboundary cooperation on water scarcity and drought issues, which are generally important for mountain regions and river basins in Europe. Based upon the illustrative regional case studies and information stemming from broader research into water resource management and adaptation to climate change, the following points can also be taken as overall recommendations for other mountain regions:

- Dialogue between all relevant stakeholders, constructive cooperation between the actors as well as efficient knowledge transfer are key factors in successful adaptation management.

- The general political and socio-economic conditions of the region, as well as other relevant frameworks, have to be taken into account. Possible drivers and barriers should be addressed during the preparation of an adaptation strategy, including political, legal, technological, institutional and organisational as well as socio-economic factors.

- The first step in developing an adaptation strategy should be an analysis of the situation, current conflicts, future changes, potential conflicts, and acceptable risks to estimate the vulnerability of the region to climate change.

- Knowledge deficits about the future impacts of climate change might be much greater in other mountain regions than in the Alps. Although this uncertainty exists, the precautionary principle requires that adaptation actions have to be undertaken because the general trends are known. The need for taking precautionary action relates to the danger of the potential for damage.

- Uncertainty exists about the goals and risk acceptance of the decision-makers. To reduce this uncertainty, a participatory decision processes should be used to clarify the priorities and motivations of the stakeholders at the beginning of the adaptation process.

- Adaptive management strategies should include participative, monitoring and iterative elements to be able to flexibly adjust adaptation decisions and measures to new conditions. Such an adaptive adaptation process must be based on continuous monitoring and research to enable continuing learning.

- The problems and the importance of the different sectors and the need for specific adaptation measures may differ between regions, (e.g. the relevance of the transport issue). In some mountain regions the need for financial support, in particular, and for organisational or technical support might be greater than in the Alps.

- The importance of local to inter-regional cooperation depends on the spatial range of the measures, e.g. the dialogue between up- and downstream regions should be considered. Also the importance of cross-sectoral cooperation, for example through regional cooperation platforms, depends on the scale and effects of the measures. Integrated Water Resources Management is a helpful approach to integrate different sectors and stakeholders.

- Adaptation options could be ranked on the basis of the available information about costs, benefits and barriers. Measures could be implemented step by step, beginning with win-win or no-regret options, e.g. water saving measures. Next to short-term measures, long-term measures should also be considered to prevent water resource issues, to improve the resilience of water resources, to prepare for and respond to problems, and to help water resources recover after problems have occurred.

The aim of multilevel governance is the coordination and integration of a multitude of stakeholders from different levels of politics and management (local, regional, federal, national and/or EU) as well as from different sectors and regions. The participation of stakeholders is important to integrate knowledge and experiences from different fields to convey a mutual understanding of different perspectives on adaption problems. Involving stakeholders is also important in order to prevent cross-sectoral and inter-regional conflicts. Thus, multilevel governance can help to improve the cooperation between different sub-regions of a mountain region, such as to reach agreement on the use of common water resources. It also promotes cooperation between different mountain regions by sharing knowledge about climate change, its impacts and adaptation options. This report can be seen as part of such a multilevel governance approach and an offer to share the existing knowledge about adaptation to water resource issues in the Alps.

Annex 1 Glossary of key terms

Adaptation:
Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation. Adaptation can reduce vulnerability of a system and depends on the adaptive capacity of the system.

Adaptive Capacity (in relation to climate change impacts):
The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. The adaptive capacity of a social system is determined by its institutional and economic capacity as well as its willingness to adapt.

Adaptive management
This approach — often applied when the knowledge base for management decisions is incomplete and uncertain — enables the decision-makers to change former decisions and adaptation measures based on new knowledge in a continuing learning process. This 'learning by doing' will serve as an important source of information on how best to monitor the results of management and evaluate whether established goals are being attained.

Ecosystem approach:
The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organisation, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of many ecosystems. The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning. Priority targets are conservation of biodiversity and of the ecosystem structure and functioning, in order to maintain ecosystem services.

Ecosystem services:
Ecological processes or functions having monetary or non-monetary value to individuals or society at large. There are (i) supporting services such as productivity or biodiversity maintenance, (ii) provisioning services such as food, fibre, or fish, (iii) regulating services such as climate regulation or carbon sequestration, and (iv) cultural services such as tourism or spiritual and aesthetic appreciation.

Integrated assessment:
An interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines so that all relevant aspects of a complex societal issue can be evaluated and considered for the benefit of decision-making.

Integrated water resources management (IWRM):
The integrative and long-term IWRM framework promotes coordinated development and management of water, land and related resources to maximise economic and social welfare in an equitable manner without compromising ecosystems sustainability.

'No regrets' policy:
A policy that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs.

Scenario:
A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative storyline'.

Uncertainty:
An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g. a range of values

calculated by various models) or by qualitative statements (e.g. reflecting the judgement of a team of experts).

Vulnerability:
Vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. In the context of this study, we focus on the adverse effects of climate change, climate variability and extremes on water resources, including problems of water scarcity and water quality.

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Chapter 5 The regional perspective

Section 5.1 Overview and methodology of regional case studies

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Section 5.2 Joint efforts against water shortages — River Lavant valley in Carinthia (Austria)

Most of the findings in this chapter on the River Lavant valley are based on results of the ClimChAlp project, 'Climate Change, Impacts and Adaptation Strategies in the Alpine Space'. The project ran from 2006 to 2008 and was carried out in the framework of the Community Initiative INTERREG III B. A total of 22 partners from seven alpine countries worked together to identify ways for communities to successfully cope with climate change impacts whilst ensuring sustainable development in the area. Based on the results of the project, the transnational ClimChAlp consortium developed overall recommendations for policy makers, administration and stakeholders.

Further material for the case study derives from two guideline-based interviews with stakeholders from the forestry and water supply sector: 30 September 2008, interview with Hans-Georg Jeschke, district forest authority Wolfsberg; 1 October 2008, interview with Hans Hofer, head of water association network Lavant valley.

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Section 5.3 The Valais — an inner-alpine valley traditionally adapted to arid climate (Switzerland)

This case study is based on a literature review and 14 guideline-based interviews with stakeholders from different sectors and from public authorities and was conducted in September and October 2008.

Public authorities in the Valais: Department of Spatial Planning, Department of Forest and Landscape, Department of Agriculture, Department of Energy and Hydro-power.

Organizations: Chamber of Agriculture Upper Valais, Valais Tourism, Unternehmen Goms. NGOs, private and semi-public enterprises: WWF, Energy West Switzerland (EOS), Electric utility Brig-Naters.

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National Research Programme NRP61 „Sustainable Water Management", Swiss National Science Foundation: www.nfp61.ch.

Section 5.4 A long history of adaptation — water availability in South Tyrol (Italy)

The work for the South Tyrol case study was performed in the framework of a regional research project on climate change in South Tyrol financed by the Province of Bolzano.

In the context of this project nine guideline based interviews were conducted with responsible representatives of the authority, stakeholders from different sectors (energy and hydropower, environment, agriculture, forestry, tourism) and private enterprises (September to November 2008).

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Section 5.5 Savoy — balancing water demand and water supply under increasing climate change pressures (France)

The results presented in this chapter on Savoy are mainly based on a literature review, the report of the APTV 2007, a synthesis of the study in 2008. The APTV study includes 17 interviews with different stakeholders in the field, mainly politicians, environmental protection and water associations, the tourism industry including in particular the ropeway associations, historians, the hydroelectric sector (EDF), the Chamber of Agriculture and water agencies. They were undertaken during the month of August 2006.

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Section 5.6 The secrets of Vienna's high water quality (Austria)

The findings presented in this chapter on the Mt Hochschwab, Mt Rax, Mt Schneeberg and Mt Schneealpe valley are mainly based on results of the KATER I and KATER II projects. KATER I (from 1998 to 2001) and KATER II (from 2003 to 2006) stand for the 'KArst waTER research programme', which was funded by the European Union. Partners from Austria, Italy, Slovenia and Croatia worked together on the issue of protecting karst water systems, which are of crucial importance for the supply of drinking water worldwide. Both projects aimed to safeguard water supply and catchment areas by managing land-use activities, water management and environmental protection in sensitive areas. The development and implementation of a decision support system was recommended to optimise decision making processes, and was accomplished within the projects. The Austrian partner — the Vienna Water Works — analysed these questions in the case study area of Mt Schneeberg, Mt Rax, Mt Schneealpe and Mt Hochschwab.

Furthermore, the case study is based on three guideline-based interviews with stakeholders from the water supply sector and from the field of ecosystem science: (1) Interview with Dr. Gerhard Kuschnig, Vienna Water Works, 26th August 2008 and 26th November 2008; (2) Interview with Christina Schartner, Masters student working on Climate Change Impacts on Hydrological Parameters, 26th August 2008; (3) Interview with Dr. Thomas Dirnböck, Environmental Agency Vienna, 3rd September 2008.

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Chapter 6 Adaptation in vulnerable alpine regions — lessons learnt from regional case studies

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Chapter 7 Adaptation at the European scale — cooperation with alpine water towers

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Mountain Partnership: www.mountainpartnership.org/.

The Danube River Protection Convention: www.icpdr.org/.

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