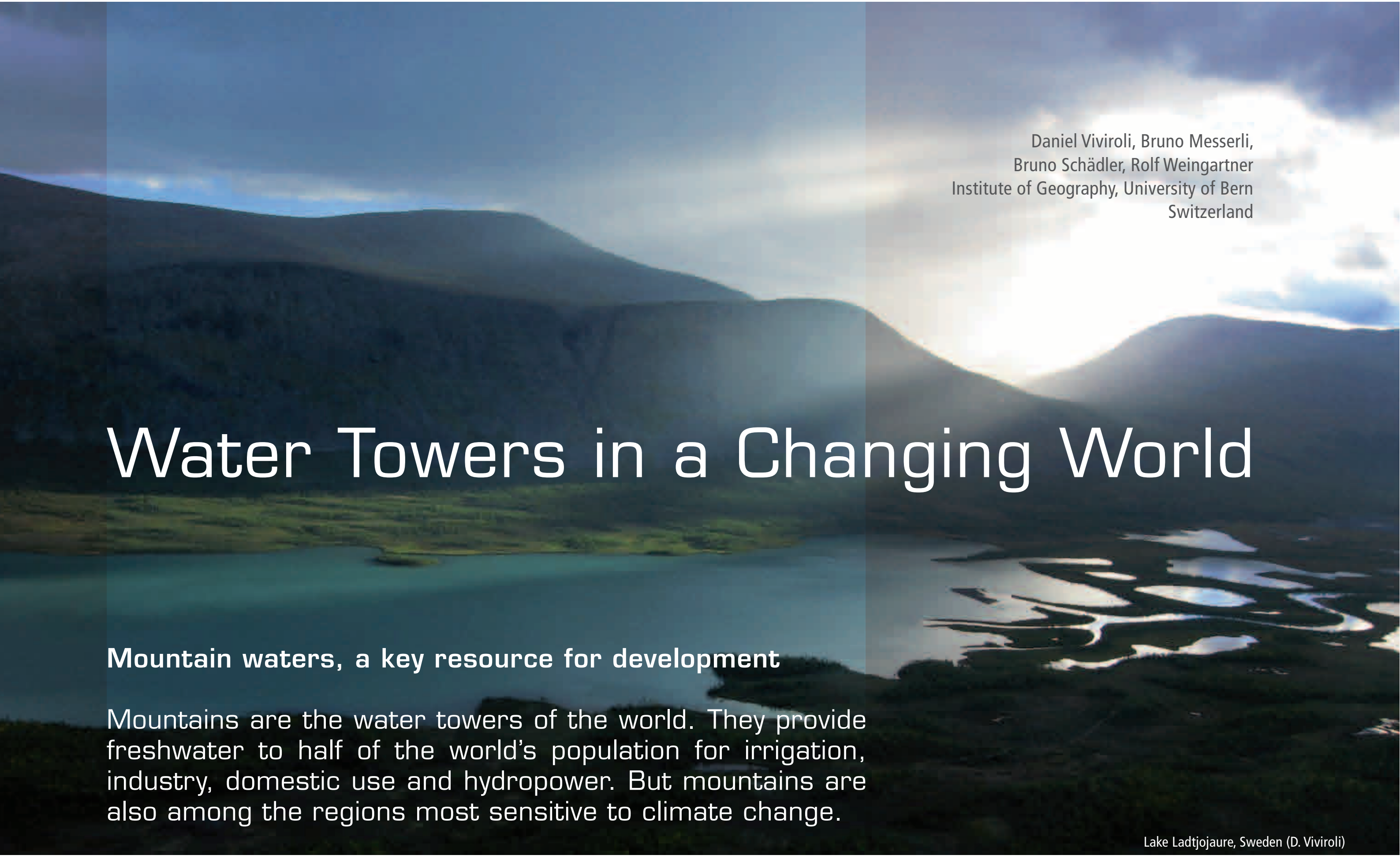
2 Mountain Waters

Tarfala Valley, Lapland, Sweden (D. Viviroli)



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Water Towers in a Changing World

Mountain waters, a key resource for development

Mountains are the water towers of the world. They provide freshwater to half of the world's population for irrigation, industry, domestic use and hydropower. But mountains are also among the regions most sensitive to climate change.

Lake Ladtjojaure, Sweden (D. Viviroli)

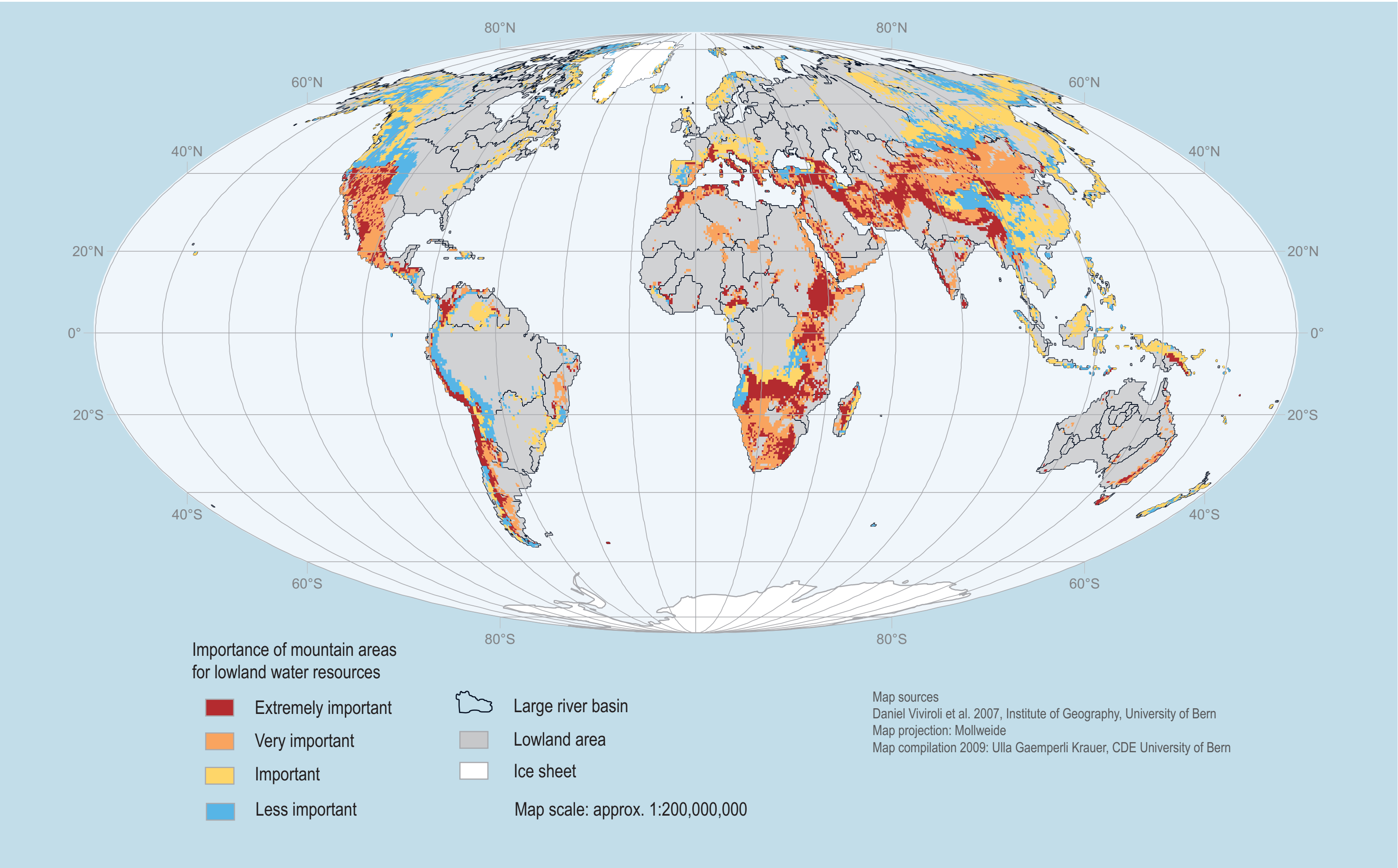
Global assessments of mountain water resources are challenging owing to the limited data available. An initial comprehensive global overview was recently created based on a set of global maps at a resolution of 50 × 50 km^2 (Figure 2.1; Viviroli et al 2007). Analysis of this overview shows that even in temperate climates, which are relatively water-abundant, mountains deliver about twice as much runoff per unit area as lowlands. In arid zones, mountains provide as much as 7 times more runoff than lowlands; in these dry water-scarce zones, mountains frequently contribute as much as 90% or more to the total runoff of a river basin (Figure 2.2, Viviroli et al 2003). The importance of mountains is particularly pronounced in subtropical regions with a high variability of precipitation, especially if they depend on a single rainy season. Cases in point are the countries of monsoon Asia, such as India and Pakistan, as well as Southeast Asia and southern China, where about 1.3 billion people or close to 20% of the global population depend on mountain waters from the Himalaya, Karakoram, and Tien Shan massifs and from Tibet. Other large mountain systems critically important for water supply are the Rocky Mountains, the Andes, the mountains of the Middle East, the Atlas Mountains, and the mountains of South Africa. In addition, a number of regional 'water towers' found on each continent play a key role. In East Africa, for example, Mount Kenya is the only source of freshwater for over 7 million people.

Implications of climate change

Temperature and precipitation in the form of rainfall and snow largely determine the hydrological cycle, including runoff. Changes in these factors will thus impact freshwater supplies from mountain areas and have implications for water availability in the lowlands. Snow cover is particularly sensitive, as it reacts quickly to changes in temperature. In a warmer world, a smaller fraction of winter precipitation will fall as snow, and the melting of winter snow will occur earlier in spring. This will lead to a shift of the seasonal runoff maximum to winter and early spring. At present, the seasonal maximum occurs in summer and autumn, when demand in the surrounding lowlands is highest. Where no sufficient storage capacities are available, much of the winter runoff will flow directly to the oceans. Such changes in seasonal maxima, predicted by the IPCC with high confidence, have already been observed in some regions such as the Rocky Mountains and the European Alps. Their future impacts are likely to be severe, since more than one billion people, or one-sixth of the earth's population, rely on snow-melt dominated runoff for their water supply (Barnett et al 2005). To this the impact of shrinking glaciers will be added, which is more limited to mountain regions but has the potential to jeopardise large irrigation systems that rely on glacier melt runoff, such as those found in the mountains and forelands of the Andes. Regions where the water supply is dominated by snow and glacier melt, such as the Hindu Kush-Himalaya and the Rocky Mountains, will also be highly vulnerable, particularly where water systems are already over-allocated, as in the Western US (e.g. Columbia River) and Canada. Although adaptation of these systems appears to be possible by building up infrastructure such as dams, this will be expensive; moreover, it will have unknown impacts on societies and ecosystems downstream.

Changes in water availability due to climate change are taking place at a time when pressure on water resources for irrigation and food production, industrialisation and urbanisation is increasing. The effect will be the greatest in semi-arid regions and in the monsoon belts, especially during seasonal deficits which have been covered by water supply from mountains until now. These changes will give new impetus to the construction of dams and water transfer systems. India and China, for example, are planning or already implementing large interbasin schemes to transfer water to water-scarce regions, the effects of which are difficult to anticipate. If these two schemes are realised, more than two billion people will depend on water originating in the Hindu Kush-Himalaya.

Figure 2.1: Importance of mountains as "Water Towers" of the world (Viviroli et al 2007).



The way forward

Projections of climate change and its impacts remain a challenge due to the highly non-linear interactions of the relevant factors. This is especially true for mountain regions with their marked topography, which is not well reflected in present climate models. Mountains can alter atmospheric circulation and hence rainfall patterns and snow cover beyond current predictions and over large areas, for example in the Hindu Kush-Himalaya region, where the interplay of the Indian summer monsoon and the winter westerlies over Tibet is little understood. In light of such knowledge gaps, global climate models and predictions of future freshwater supplies are subject to great uncertainty.

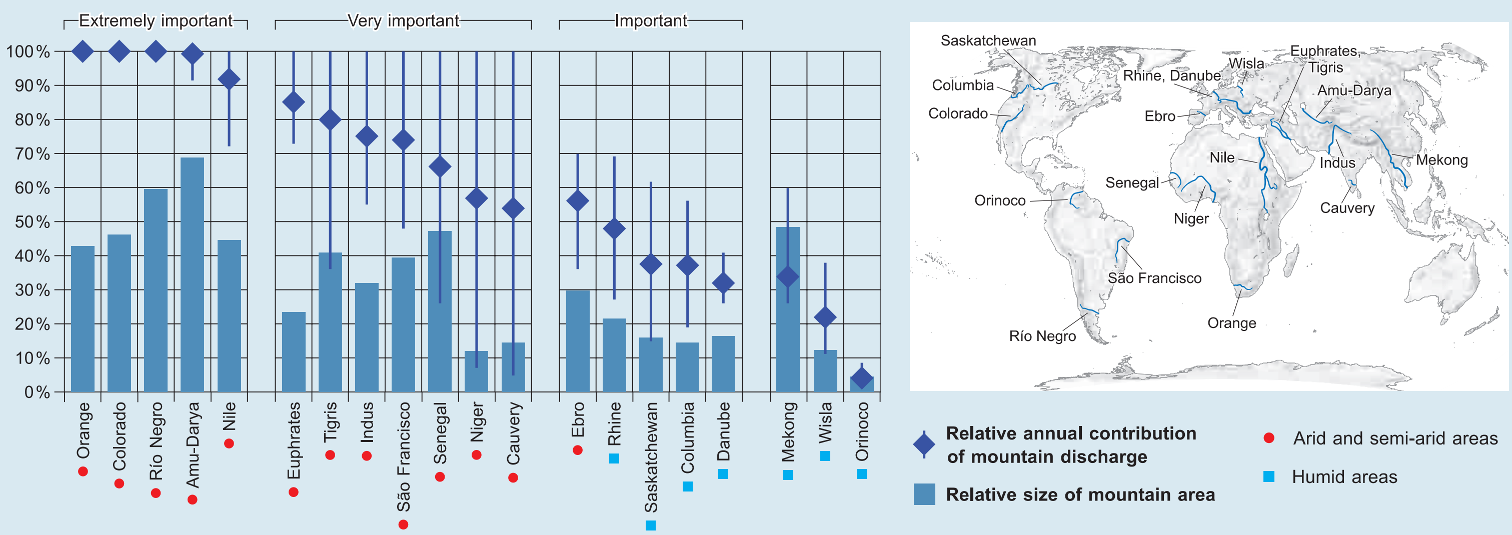
In a world of growing water scarcity, it is urgent that we improve our knowledge of present and future mountain water resources and freshwater supplies. This necessitates investment in long-term high-altitude observatories, especially in mountain areas in the developing world, where they are few and far between; the current trend of closing down monitoring networks due to high operating costs must thus be reversed. While monitoring is essential, it is not enough. Public access to data

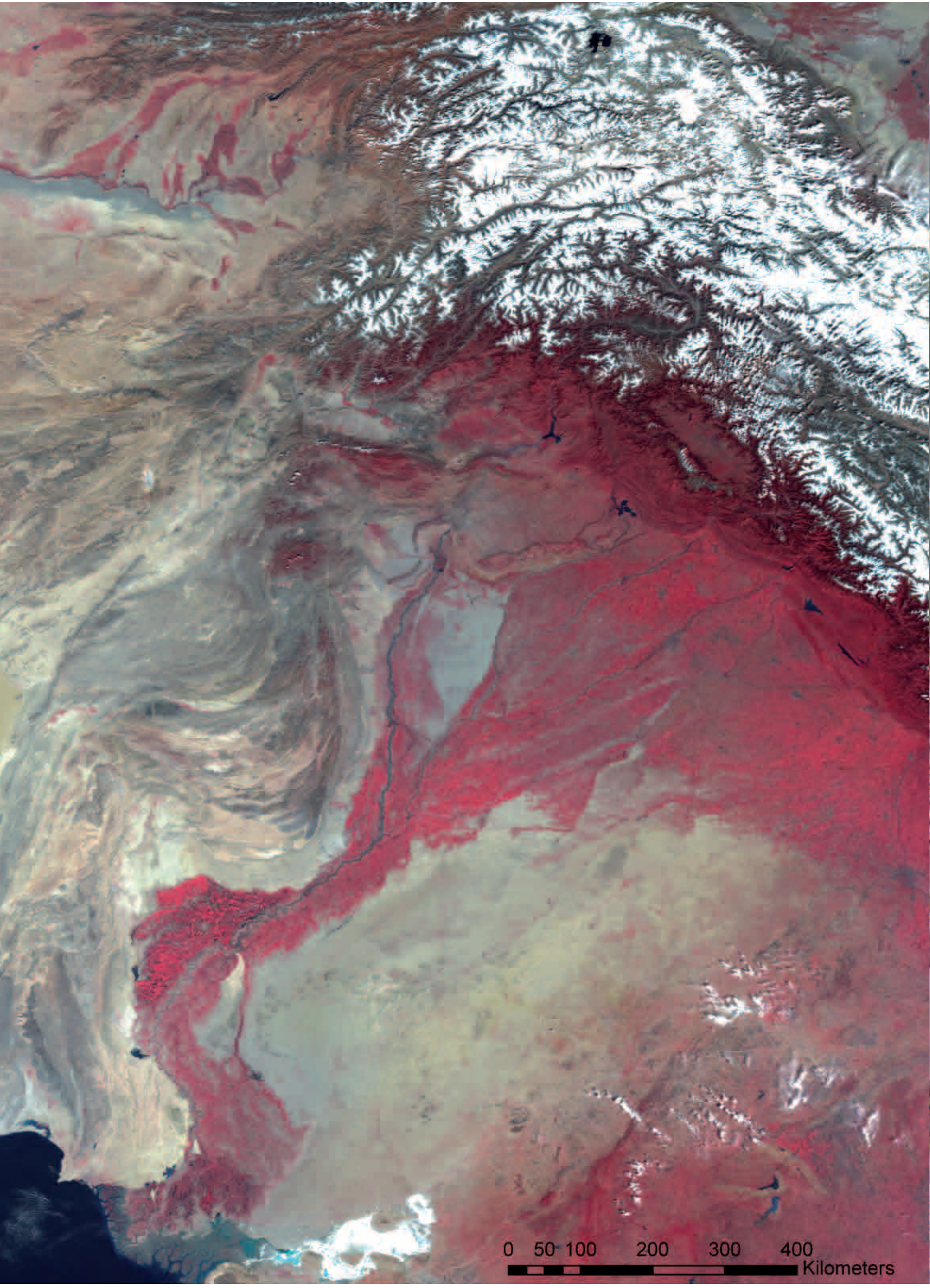
Mountain waters on the global agenda

The importance of mountains in their role as headwaters and sources of water for the often densely populated surrounding lowlands has long been recognised by the scientific community. Since the 1992 Rio Earth Summit, this importance has increasingly become the focus of political attention, even more so during the International Year of Mountains in 2002 and the subsequent International Year of Freshwater in 2003. The Intergovernmental Panel on Climate Change (IPCC) stated in 2007 that mountain regions will be particularly affected by climate change, and that changes in the water cycle can already be observed in these regions.

In 2008, the UN General Assembly adopted Resolution 62/196 on Sustainable Mountain Development, stating that "The UN General Assembly notes with appreciation that a growing network of governments, organizations, major groups and individuals around the world recognize the importance of the sustainable development of mountain regions for poverty eradication, and recognizes the global importance of mountains as the source of most of the Earth's freshwater [...]".

Figure 2.2: Contribution of mountain area to total discharge, and size of mountain area as compared to total basin area for selected rivers world-wide (Viviroli et al 2003).





In the Hindu Kush-Himalaya (H. Rueff)

Left: This false colour infrared satellite image shows the Indus Basin in Pakistan. The irrigated area (in red) is one of the largest in the world. It ensures the country's food supply and generates 23% of its GDP. 80% of the waters that feed the basin are provided by seasonal snow and ice melt in the Hindu Kush-Himalaya mountains (in white at the top of the image). Source: NASA/GSFC, MODIS rapid response/1.10.2002

on water resources, where they exist, must be improved and current restrictions imposed for strategic reasons must be removed. Investment in infrastructure, technology, and international collaboration, as well as a shift in water management from the supply side to the demand side, will be necessary in order to share future water supplies from mountain areas equitably and sustainably.

Vulnerability of snowmelt-dominated regions to climate change

"Geographic areas where snowmelt hydrology dominates the water cycle are expected to be especially vulnerable to climate change because a warming climate, which is projected with high certainty for the twenty-first century, directly affects the seasonality of runoff, generally shifting runoff from the warm season to the cool season." Adam et al 2009.

European Alps: A Water Tower of Continental Europe

In the European Alps, melting of snow and ice produces high, reliable discharge in summer, supported by low evaporation due to high elevation. This discharge levels out the more variable runoff that forms at lower altitudes, where precipitation is more irregular.

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As a result, the mountainous sections of the four main rivers, the Rhine, Danube, Po and Rhone, contribute about twice as much runoff as would be expected on the basis of their surface area. In the summer months, their contribution to overall discharge is even greater, reaching 80% in the case of the Po (see Table 2.1). Where international cooperative water management is concerned, the Rhine River basin is exemplary: Since the 1950s, the International Commission for the Protection of the Rhine (ICRP) has successfully coordinated the actions of nine countries, as well as the European Commission, with respect to sustainable development, water quality, flood prevention, and protection. The ICRP has served as a model for other large river basins, and similar approaches are urgently recommended for other transboundary rivers. With regard to climate change, the ICPR initiated a scenario study on future water resources and changing flow regimes in 2007. Based on the results, adjustment strategies for integrated water management in the River Rhine basin will be proposed.

Table2.1: Freshwater contribution of the European Alps to total discharge of the four major Alpine rivers.

River	Mean annual contribution from mountain area to total discharge	Maximum monthly contribution from mountain area in summer (Jun-Aug)	Share of mountain area in total basin area
Danube	26%	36%	10%
Po	53%	80%	35%
Rhine	34%	52%	15%
Rhone	41%	69%	23%

Water and Climate Change in the Tropical Andes

As glaciers are melting away in the tropical Andes, water regulation and storage capacity may shift to other areas such as mountain wetlands in the *Páramos* and *Punas*. These high-altitude landscapes with their moors and lakes are very vulnerable to human perturbation including land cover change, pollution, and destructive recreation.

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Pàramo near Cuenca, Ecuador (W. Buytaert)

Their management and use is thus increasingly important, but also delicate as it has to strike a balance between safeguarding water supply for downstream regions while securing economic benefits for local communities. The *Proyecto Páramo Andino* has taken up this task with funds from the Global Environment Facility (GEF). Implementation was started in 2006 by CONDESAN with the support of governments, research institutions, local NGOs, and the population. The project has sites in Venezuela, Colombia, Ecuador, and Peru. An important component is participatory environmental monitoring, including data collection on precipitation and river flow, which helps farmers improve irrigation schedules and water supply systems. Such data are also essential for negotiating compensation for environmental services, which can help diversify local incomes and make farmers more resilient to the anticipated effects of climate change.

In other areas, farmers have become active on their own initiative. A striking example can be found in the basin of the Laguna de Fúquene in Colombia, which is inhabited by about 115,000 people: The potential threats of climate change have prompted farmer communities to join forces to make current water resources more resilient to potential future changes. Without government support, they have raised money to buy crucial wetlands, reforest degraded areas, and decrease water loss in canals and pipe systems. Awareness campaigns encourage households to reduce their water consumption.

Climate Change Action in the Columbia Basin in Canada

The Columbia River in western North America originates in British Columbia, Canada, and flows into the Pacific Ocean in Oregon, USA. The river is 2000 km long and has more than 40 major hydropower stations that produce most of the electricity for the Pacific North-West.

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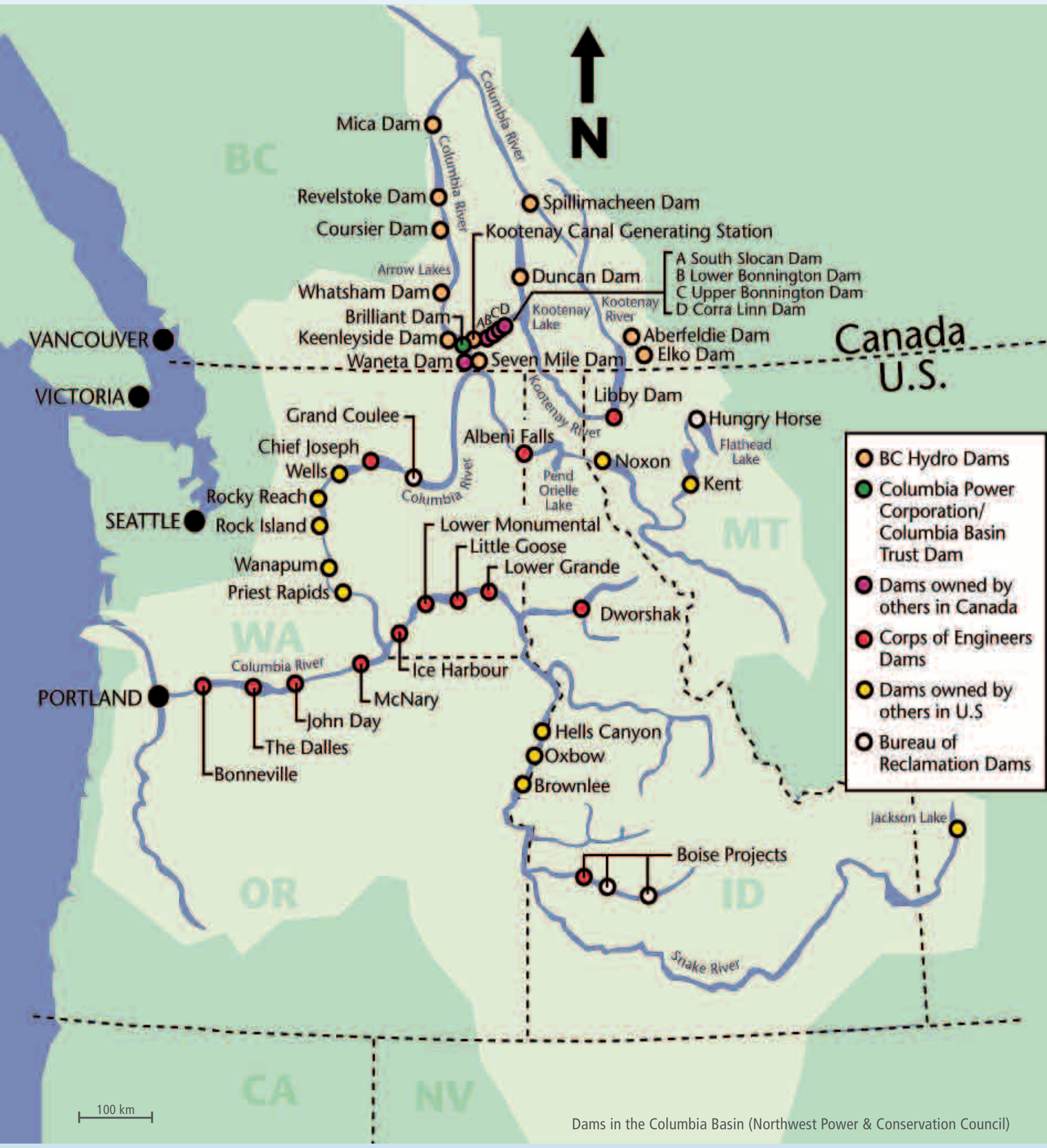
Waneta Dam (Columbia Basin Trust)

The Canadian portion covers 15% of the total watershed but provides approximately 40% of the total annual stream flow. In 1964 Canada and the USA ratified the Columbia River Treaty (CRT), a unique bi-lateral water management agreement that dealt with water storage for optimisation of power production and flood control on the entire Columbia River system. The centrepiece of the Treaty was the creation of three major water storage dams in Canada. In return, the US as the downstream nation agreed to compensate Canada as the upstream nation for the service of water storage for flood protection and hydropower generation. The Treaty provides that after 60 years either party may consider its termination or re-negotiation. Thus the agreement will come up for renewal in 2024, provided that 10 years' prior notice is given by either party in 2014.

No one was aware of climate change in 1964. In recent years, however, concerns have been expressed about the implications of global warming for the basin's hydrology and the resultant vulnerabilities of the system's services. Given concerns about glacial recession, changes in snow cover, possible shifts in streamflow regimes and higher rainfall and runoff variability, the Columbia Basin Trust (CBT) has initiated an aggressive climate change-related research, adaptation and mitigation strategy with a specific focus on community involvement. Since 2006, the following major programmes have been put in place:



Dams in the Columbia Basin (Northwest Power & Conservation Council)


Mica Dam (Columbia Basin Trust)

1. Climate-related research to understand predicted hydrologic changes in the Canadian Columbia Basin;
2. Development of a community watershed network that focuses on water quality monitoring and stream rehabilitation. 12 community teams have been trained to produce scientifically sound datasets on stream flow, water quality and ecosystem health;
3. A water-smart initiative to aggressively pursue water conservation practices for domestic, recreational and industrial use, with the aim of reducing water consumption within the basin by 20% by 2015;
4. Development of climate change adaptation strategies for mountain communities. This project started in 2007 with two mountain communities. The aim was to develop a methodology that can be used to identify the risks faced by increased climatic variability. A multi-stakeholder process was used to determine and prioritise the risks and to develop protective measures to minimize possible impacts. In 2009 two additional communities and one regional district were chosen to engage in a similar process, and it is anticipated that by 2014 all mountain communities in the basin will have Climate Change Adaptation Plans in place.
5. An innovative program was also initiated to monitor carbon emissions and reduce the local government corporate carbon footprint in each of the 25 municipalities and 3 Regional Districts in the Basin.

The Columbia Basin Trust has taken the lead in supporting community-based initiatives that have a large public education component, involve academic institutions and researchers, engage community volunteers, and assist municipal governments in putting climate adaptation and mitigation efforts into action.