Sights Set on Alpine Water Treasure

Water plays a determining role in the Alpine region: it represents untouched nature, sensitive ecosystems, and a resource that can be used in many different ways. These natural and utilitarian values are being threatened or destroyed by one-sided and intensive use. The alpine regions are, therefore, challenged to manage their water resources in a sustainable manner. At the same time, it is essential that interests are coordinated across national boundaries. Millions of people live along European rivers and depend on these alpine water resources. In light of predicted global warming, international cooperation is becoming ever more important.

The Swiss Alps are rich in streams and rivers and represent a "treasure chest" of water for vast areas of western Europe. These water resources are intensively used for electric power generation and, in an effort to both protect against Nature's forces and reclaim land, many streams and rivers have been corrected. Utilization and protection interests are often in acute conflict with the values of sensitive aquatic ecosystems and natural landscapes. What is needed is a balanced consideration of the various interests, with the goal of protecting valuable natural characteristics while also securing important uses. This requires comprehensive management approaches that are effective at different levels and that must have a solid scientific basis.

The Living Space Alps

The Alps comprise an area of roughly 190 000 km^2 divided among eight countries – France, Italy, Monaco, Switzerland, Germany, Liechtenstein, Austria and Slovenia (Fig. 1). Switzerland's share of the Alps covers 25 000 km^2, which corresponds to 60 % of Switzerland's total area. The lowest point of the Swiss Alps (Fig. 2 and 3) is on Lago Maggiore with an elevation of 193 m a.s.l.; the highest point is the Dufour peak at 4634 m. Within very short distances, we find enormous climatic differences: dry intermountain areas, Mediterranean zones, and every possible transition zone all the way to polar zones. Average annual precipitation ranges from 500 to 4000 mm.

The huge variability in natural conditions, as well as agricultural practices that are often still near-natural, gives rise to a wide spectrum of habitats for fauna and flora. This is why areas of high species diversity, so-called "hotspots", are found primarily in the Alpine region in Switzerland. An abundance of relics allow us to reconstruct the historical development of the Alps since the last ice age.

The population density in the Alps is generally low. The entire area of the Alps is inhabited by almost 14 million people. Of the Swiss population, only about 1.6 million people, or 22 %, live in the Alpine zone [1]. With 26 people per km^2 and many unpopulated high mountain areas, the Canton of Grisons has a particularly low population density; in contrast, it can reach 400 people per km^2 in some of the larger valleys. Valley bottoms are not only used intensively for agriculture, but are also populated by industrial activity. At the same time, they are the main corridors for roads and trains which also play an important role in international transportation.

Agriculture was the dominant economic factor in most alpine areas as little as 100 years ago. Since then its importance has dropped dramatically, and the population living from agriculture only accounts for a few percent. Depending on the elevation, the dominant cultivation includes fruit trees, crop farming or grass production and grazing. In large areas, particularly in Ticino, Valais and the Grisons, land is becoming increasingly abandoned. The tourism and leisure activity sectors, on the other hand, have gained enormously. Today, between 10 % and over 20 % of the jobs in mountain regions are related to these sectors.

A Treasure Chest of Water

The Swiss Alps are the source for the large rivers Rhine and Rhone as well as the Inn and the Ticino, which are important tributaries of the Danube and the Po. Average rainfall in this area is 2000 mm with some 1175 mm of this precipitation, or approximately 28 km^3 or 900 m^3/s, running off into neighboring areas. Some 24 % of the water the Rhine releases into the North Sea originates in the Swiss Alps. For other rivers, this proportion amounts to only 1–10 % (Tab. 1), nevertheless discharge from the Alps plays a major quantitative role in long sections of many rivers.

Fig. 1: The Bow of the Alps.

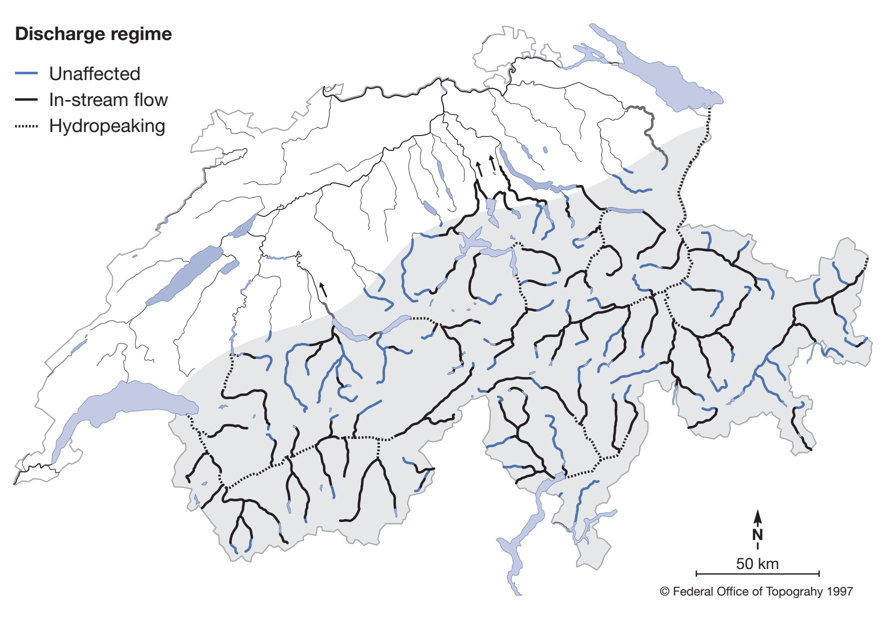

Fig. 2: Alpine streams and rivers affected by hydroelectric power generation. Adapted from [14].

The Alps also represent an enormous water reservoir. Approximately 74 km^3 water are stored in Swiss glaciers at the present time; in 1901, the volume still was 95 km^3 [2]. Natural lakes, including lakes along the periphery of the Alps (counting only the Swiss portion in the case of lakes crossing national borders), hold approximately 100 km^3, while artificial storage lakes add just under 4 km^3. Snow is another water reserve, although it is accumulated and released on an annual basis. Very large but hardly assessable water reserves are located in various underground systems, such as in recent gravel deposits in valley bottoms or in pores and fractures in rock.

Water – Pivotal for Alpine Nature

The Swiss Alps contain 30 000 km of streams and rivers as well as 17 natural and 47 artificial lakes with a surface area of more than 0.5 km^2, not to mention innumerable smaller mountain lakes. Glaciers currently cover an area of 1300 km^2, which corresponds to roughly 5 % of the alpine zone.

Alpine streams have many different faces: not only quiet springs, mellow lake outlets, steep whitewater streams, meandering networks of stream channels in flood plains, roaring waterfalls, glacier streams that rage at certain times and are calm at others, but also streams flowing over artificial steps, confined by hard banks or even stream channels suffering from total withdrawal of water. Streams are classified according to the origin of the water: glacial melt water, ground water, rain or snowmelt water. The various types of streams represent different habitats and are characterized by their hydrology, morphology, physical appearance and chemical composition. Climatic and topographic barriers lead to fragmentation, creating an array of habitats and biotic communities [3] (see article by M. Hieber on p. 9). High alpine lakes are extreme ecosystems that are shaped by their harsh climatic conditions, scarceness of nutrients and low salinity. They are not, however, too remote to receive input of anthropogenic chemicals. Pollutants are transported via the atmosphere and deposited in high alpine areas (see article by R. Psenner on p. 12). Dominant elements of both the landscape and hydrologic system are the large lakes on the periphery of the Alps: Lake Geneva, Lake Constance, Lake Lucerne, Zugersee, Walensee, Brienzersee, Thunersee, Lago di Lugano and Lago Maggiore.

Alpine streams, as well as high mountain lakes, are very sensitive to both climatic changes and anthropogenic impacts (see article by M. Sturm on p. 15).

Human Society Benefits from Abundance of Water

In the Swiss Alps, one use dominates the interest in our water resources: energy production. Almost 60 % of Switzerland's electricity requirements are being met by hydroelectric power generation. The majority of this power is produced in the Alps whereas their usable potential is largely realized. Other important uses of our streams and rivers are the supply of drinking and process water for towns, tourist centers and industry, and the disposal of waste water where streams and rivers act as receiving media and transport vehicles.

Irrigation in agriculture has a long tradition, particularly in the dry valleys of the inter-mountain region. The best known example is probably the irrigation system in the

Rivers Swiss Alps	Main river	River mouth	Discharge from		Portion of Swiss Alps at	
			Swiss Alps	entire WS	entire WS of main river	annual discharge at river mouth
Rhine-Aare WS*	Rhine	North Sea	1238 mm/Jahr 530 m^3/s	309 mm/year 2200 m^3/s	6 %	24 %
Rhone	Rhone	Mediterranean	1100 mm/Jahr 182 m^3/s	611 mm/year 1900 m^3/s	5 %	10 %
Ticino WS**	Po	Adriatic (Mediterranean)	1239 mm/Jahr 134 m^3/s	657 mm/year 1460 m^3/s	5 %	9 %
Inn	Danube	Black Sea	876 mm/Jahr 54 m^3/s	253 mm/year 6450 m^3/s	0.2 %	1 %

* Rhine, Thur, Linth, Aare, Emme, Reuss, etc. / ** Ticino, Maggia, Tresa, etc.

Tab. 1: Hydrological relevance of the Swiss Alps. Rivers originating in the Swiss alpine region [15]. WS = Watershed.

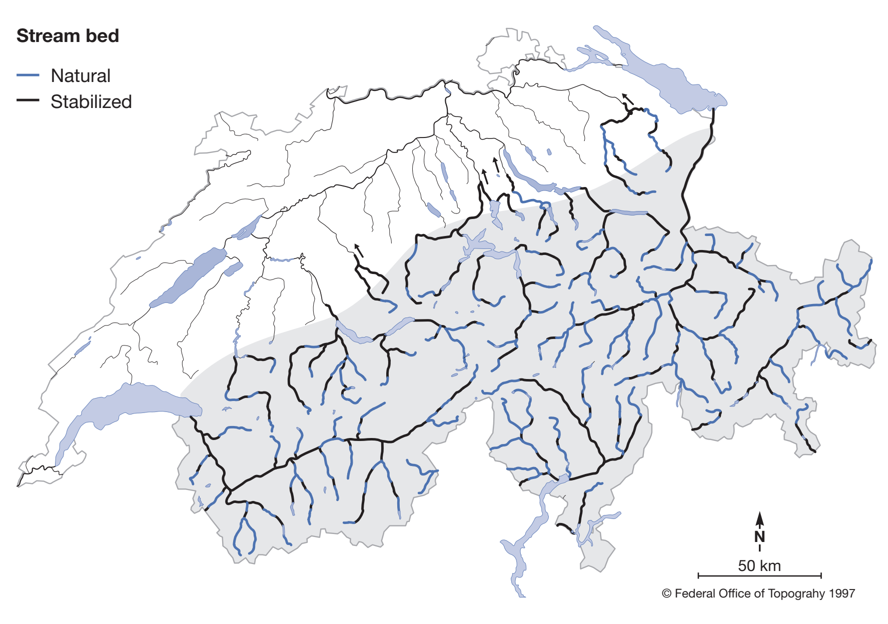

Fig. 3: Alpine streams with corrected stream bed. Adapted from [14].

Valais, where irrigation canals have been used for several hundred years. The water is usually caught high up in the mountains and piped across extremely difficult terrain down to fields and pastures along the valley floor. Ditches and pipes in the Valais total some 1500–2000 km and irrigate an area of 140–200 km^2 [4]. One use of our streams that is no longer practiced is the drifting or floating of logs, although it was common well into the 20th Century. This often required hydrologic engineering, such as retaining basins or sluices for directing the logs [4].

In addition, streams offer a multitude of opportunities for recreational and sporting activities. They enrich the landscape, are essential for human well being, and are often the source of strong emotions. A diverse landscape and intact streams increase the recreational value of a region. On the other side of the coin, however, increased recreational use places increasingly higher demands on the streams [5]. Streams, or water in general, can cause floods and landslides, thus posing a serious threat to human life and economic values.

Utilization Impacts Water Bodies

The production of hydroelectric power requires a number of different production and storage structures [6], resulting in operational and structural impacts that affect streams in a variety of ways (Tab. 2). Often, both infiltration and exfiltration zones are affected, which translates into changes in the groundwater regime.

Storage basins often receive water from areas which do not belong to the natural drainage area. Water is transferred within a river watershed or even between watersheds of different river systems. The Ticino, for example receives water from the areas of the Rhine, the Reuss (Aare) and the Rhone. In some cases, water is diverted across national borders; in the case of the Inn, for example, a water volume corresponding to 55 mm of precipitation in its Swiss watershed is exported to Italy [2].

In the Swiss Alps, virtually all larger and many smaller streams are affected by water withdrawal and hydropeaking (Fig. 2). The operation of storage basins can also lead to dramatic shifts in summer and winter patterns of discharge volume. This is true in the case of the Rhone and the anterior Rhine [2, 6].

Many wild streams and most of the larger rivers have been corrected (Fig. 3) for the protection of settlements from natural disasters as well as for the reclamation and safeguard of farm land. River corrections are often accompanied by the drainage of large tracts of land adjacent to the rivers. In the Swiss Alps, only a few relics of the formerly widespread flood plains remain.

The effects of hydroelectric power generation and river corrections can be felt far downstream. Most noticeable are changes in discharge patterns, particle and nutrient concentrations, and temperature regimes (see article by A. Wüest on p. 18).

Effects of Climate Change

Water regime along the rivers will be affected by climate change in different ways. Changes taking place in the Alps will be felt along the entire course of the Rhine, all the way to its mouth at the North Sea, and they will be superimposed on regional effects [7]. An increase in snow levels, larger flood events during the winter, lower discharge volumes during the summer, more dynamic discharge patterns, increased evapotranspiration, and a rise in sea level resulting in increased salinity in near-shore ground water will take place. These effects together with the changes in land use by settlements and agriculture will require modifications in

Physical and chemical effects of hydropower utilization	**Type of intervention:** Water withdrawal	Removal of sand (sand flushing)	Water return	Water storage	Structural interventions
Changes in discharge regime	P	(P)	P		
Changes in flow patterns	S		S		P
Changes in suspended solids loads	S	P	S	P	(S)
Shrinking and/or structural changes in habitat	S	S	S		P
Changes in chemistry and temperature of water and sediments	S		S	P	

Tab. 2: Primary (P) and secondary (S) effects of hydroelectric power generation on streams. S is a consequence of P.

stream management, and furthermore in all human activities related to water (see article by B. Schädler on p. 24).

Conflicts of Interest

Local and regional water interests within the Alps can get in each other's way. Often power generation and river correction are in sharp conflict with the desire for an intact, natural landscape, recreation and tourism. What concerns downstream regions, is that they depend on electricity and water for their people and industries from the Alpine regions. On the other hand, upstream manipulations can affect uses and conservation objectives along the downstream river stretches, examples include improvement of river habitat, flood protection, navigation and water supplies.

Downstream water users are becoming more sensitized to these issues, especially as they are considering the possible consequences of global climate change. The longer the more, water management in the Alps will be confronted with problems and demands of the downstream regions. However, these regions also have some responsibilities of their own. The farther they move from the sustainable use of their own water resources, the more they will depend on the importation of water as, for example, from the Alpine regions [8]. All of this demonstrates rather clearly how the different interests regarding water resources are intertwined, from the Alps all the way to the sea.

Premises for Water Management

The water of the Alps serves both Nature and society. One-sided utilization priorities – disregarding the value of a natural Alpine environment or interests of other regions – must be rejected. Much needs to be accomplished at the local, regional and international levels.

All the different interests and problems must be analyzed and evaluated at all levels – considered from the broadest possible viewpoint and then integrated into management concepts. This will require consistent political directives that can then be implemented at different levels in a step-by-step approach. This process has to provide incentives and opportunities for all participants and affected parties [9].

The Water Framework Directive of the EU regulates the integrated management of water resources in the context of large watersheds [10]. The directive is not adequate, however, to preserve the invaluable ecological resources of the Alpine region. There are a number of voices advocating that the Convention for the Protection of the Alps be supplemented by a Water Protocol. The intent is to balance the various demands that are put on our water resources and to guarantee sustainable protection and utilization (see article by M. Broggi on p. 7).

Examples of Actions

The development of a Swiss certification process for the labeling and promotion of environmentally-friendly electricity is a prime example of successful environmental optimization of a specific water use with direct involvement of the stakeholders. Ecological and economic concerns were brought together and addressed in an approach that was beneficial for all the different interest groups involved [11].

Constraints for the Third Rhone Correction in Canton Valais are given by the multiple purposes the correction is to fulfill. A balance has to be found between flood protection, improvement of the ecological viability of the river, the creation of recreational value, and economic and social demands (see article by M. Fette on p. 21).

In the case of the Rhone, the management of storage reservoirs plays an important role. In combination with retention structures, these storage reservoirs can be used to significantly reduce hydropeaking, contribute to flood protection and mitigate negative ecological effects. The ecological optimization of reservoir management is generally one of the key issues of Alpine water management in the near future.

Support by Science

Integrated approaches require contributions from a wide range of areas; physicists, chemists, biologists, hydrologists, civil and hydraulic engineers, economists and social scientists, but also energy managers, regional politicians and affected interest groups have to join in the search for and realization of viable solutions. Their actions depend on support from science. First, we need basic knowledge about the ecology of Alpine water [12] and about the effects of direct and indirect interventions. Results on these topics are presented in this issue. Secondly, science needs to aid in the development and testing of integrated management approaches where relevant political, legal, economic, institutional, social and cultural aspects are considered [13]. Scientists are challenged to wield not only their professional expertise but also their personal engagement in support of the sustainable development of our Alpine water resources.

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