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Water Supply in Alpine Environments: Analyzing Climate Change-Driven Challenges and Opportunities Based on Mountain Huts in French-Speaking Switzerland

Corentin Chofflon

Switzerland - College Saint-Michel

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Supervising teachers: Sébastien Morard and Vincent Jutzi

SUMMARY

In the course of this work, I developed a mapping tool that enabled us to take stock of the water supply situation in mountain huts exposed to the consequences of global warming.

As a result of global warming, the Alps and their weather patterns are changing dramatically. Rising temperatures are causing glaciers to retreat, but they are also encouraging the early melting of the eternal snows. In addition, drought periods are becoming longer due to changes in rainfall patterns. At the same time, public interest in mountain huts is growing, which is having an impact on their water consumption. Based on these findings, the following question was posed: what is the water supply situation in mountain huts during the summer season?

Initially, I wanted to experience the reality of caretaking for several months to understand the management and operation of a mountain hut. These experiences enabled me to get a better idea of the issues and challenges involved in supplying, managing and consuming water in these alpine establishments.

Secondly, in order to respond to the issues raised by providing an overview of the situation, I decided to develop a mapping tool that would enable me to draw up an inventory of the water supply situation in 17 mountain huts. In order to gather relevant information, the guardians of these huts were invited to complete an online survey. The guardians' opinions on the water supply situation in their mountain hut, collected through the questionnaire, form the basis of the data shown on my map.

The results show that the situation is not identical for the 17 huts surveyed. Despite a common change in climatic trends, the huts are more or less vulnerable to water shortages depending on their supply system and water management. Each hut presents a particular situation in a unique environment and context. Generally speaking, the water supply situation in mountain huts during the summer is a case-by-case affair.

In the future, the issue of water supply will become central to every community on the planet. Indeed, global warming is not a phenomenon isolated to the Swiss mountains, but one that is impacting the entire globe, independently of the region's morphology. That's why this study is so relevant. It provides a local understanding of a global problem by identifying its causes, the issues at stake and possible solutions. What's more, this local approach makes it easier for the general public to understand and become aware of a global issue.

ACKNOWLEDGEMENTS

This assessment was made possible thanks to the help of the guardians I interviewed. They took the time to fill in my questionnaire, which enabled me to obtain accurate and reliable information as well as their impressions. For this reason, I would like to express my sincere thanks to them.

I'd also like to say a special thank you to Florence and Stéphane Schenck, the guardians at Bertol hut, who hired me for three years. This experience enabled me to analyse and understand their situation in depth, with all its complexities.

I'd also like to thank the Swiss Alpine Club and my experts Sébastien Morard and Vincent Jutzi, who were on hand to answer any questions I had during the preparation of my work.

TABLE OF CONTENTS

1. INTRODUCTION

Researcher Eriksen Chritine from the EPFZ predicts a rise of 2 to 3 degrees Celsius in the average annual temperature by 2060 without efforts to reduce our greenhouse gas emissions (Eriksen 2021). The consequences of this rise in temperature are already visible in mountain environments around the world. The Swiss Alps are not an isolated case. Glaciers are retreating in both Switzerland and Greenland. In Switzerland, the volume of ice is decreasing significantly, with a mass balance that has remained negative since 2002. In 2022, Swiss glaciers will have lost 6.2% of their volume compared with 2021. In addition, the melting permafrost is increasing rock falls by destabilising rock faces (SCNAT 2022). The precipitation regime is also changing due to the physical properties of warm air, which can contain more moisture. As a result, precipitation is spaced further apart, lengthening periods of drought, and rainfall episodes become more intense. However, the total volume of precipitation remains unchanged (Eriksen 2021). What's more, according to MeteoSwiss "*snowfall is now rarer and snow stays on the ground for less time in many places than it did in the 1960s*" because the rise in temperature is also reflected in the rise in the zero degree Celsius isotherm and in the form of precipitation - solid or liquid - (MeteoSwiss 2023a). By extension, at the end of winter, the volume of eternal snow, the snow that persists during the summer periods, is thinner. On the other hand, evapotranspiration, the principle of evaporation from soils, bodies of water and plants, has not yet changed in Switzerland, but could nevertheless increase by 10% by 2060 without measures to combat global warming, leading to a drying out of the soil (Schmocker-Fackel et al. 2021).

The Swiss Alpine Club has been running 153 mountain huts throughout Switzerland since 1863. These establishments, such as those found in France and Italy, serve as refuges for mountaineers, providing them with a hot meal and bedding. In order to respect its values of sustainability, the Swiss Alpine Club modernises three to six huts a year. At the same time, the number of visitors to these modern huts is rising, as shown by the record 374,925 overnight stays in 2022 (Swiss Alpine Club SAC 2016). This influx obviously has an impact on the management of the hut, known as guarding, particularly in terms of water consumption, which is becoming a precious resource for the smooth running of the establishment. Each hut implements a water supply system adapted to its geographical location and needs. They can collect rainwater that falls on the roof, use springs or groundwater, collect water from a river, pump water from a lake, collect meltwater from eternal snow or water from glaciers (Burgi & Schneeberger 2021).

On the basis of these observations, this study attempts to answer the following question: what is the water supply situation in mountain huts during the summer season? To answer this question, which will serve as a guideline for this work, the following five hypotheses will be verified.

1. Huts fed by meltwater from eternal snow (snowdrifts) are more likely to suffer a shortage than those fed by meltwater from a glacier.
2. Larger huts are more at risk of water shortages due to higher water use.
3. Huts with only one source of supply have difficulty meeting their water consumption needs.
4. Having large reservoirs prevents shortages.
5. Modern huts are more able to avoid water shortages than rustic huts.

In order to verify these various hypotheses, the huts in the Fribourg Pre-Alps, Chablais vaudois, Bas-Valais and Central Valais were invited to complete a survey that I created. The survey was then used to draw up an overview of the water supply situation in these various establishments, creating a map that summarises and analyses the data obtained. Finally, a particular hut is examined in more detail, describing and analysing its current water supply system and its current and future solutions for avoiding water shortages.

2. METHODOLOGY

To answer the question posed by this study, I first designed a survey to gather relevant information and make up for the lack of sources, using the Microsoft tool Forms (Fig. 1). With the collected information, I drew up a map showing the current water supply situation in several mountain huts (Fig. 2). In addition, I experimented with guarding the Bertol hut during the months of July 2021, 2022 and 2023. This experience enabled me to understand how a hut works, especially in terms of water management and consumption. 17 of the 33 huts invited, located in the Fribourg Pre-Alps, Chablais vaudois, Bas-Valais and Central Valais regions, responded to my survey, which is the source of the information on my map.

The questionnaire provides quantitative data such as the altitude of the hut, the capacity in terms of number of beds, the size of the water tanks in litres and the water supply system. This information, represented by pictograms (fig. 1), is formal and therefore considered certain. In addition, the survey provides qualitative data based on the guardians' vision and perception of their hut. For example, the guardians were asked to classify the level of comfort of their establishment between rustic and modern, without any established criteria on my part. They were also asked to

identify water shortages experienced before and in 2022. Now that these events have passed, they can be proven to be certain. A final question asked the guardians to assess the future risks, in 2030, 2050 and 2100, of water shortages for their establishment. This information is represented on the map using a colour scale of low, medium and high risk (fig. 1). In addition, each guardian justified and explained their vision, their possible problems and their risk projection in the comment spaces, which enabled me to understand the reasons for their assessment. These numerous comments were invaluable to me and are included in part of my analysis.

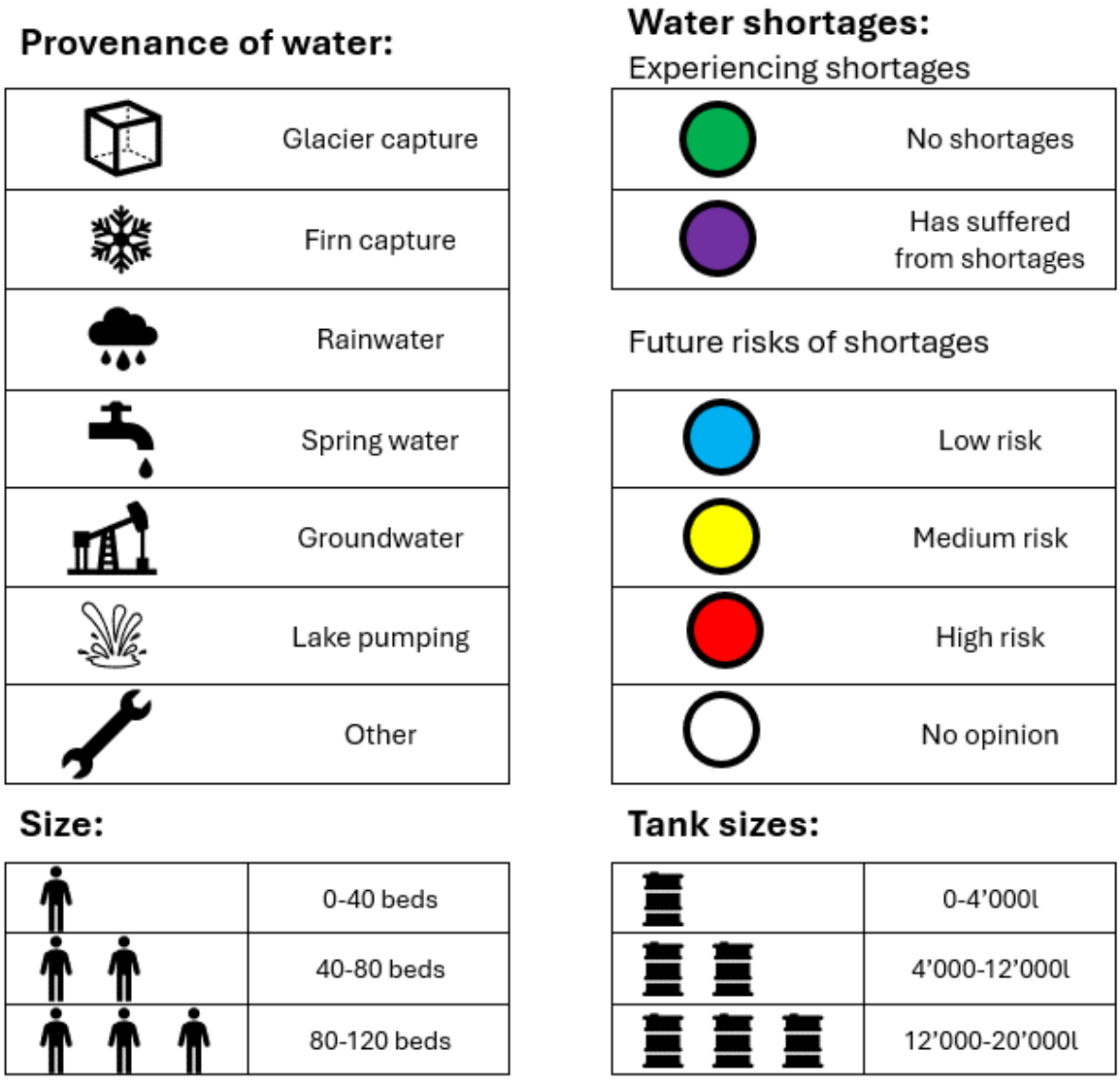

Figure 1 : Map legend. The map includes information on the water supply, past and projected water shortages, the capacity of the hut in terms of number of beds and the size of the reservoirs in litres.

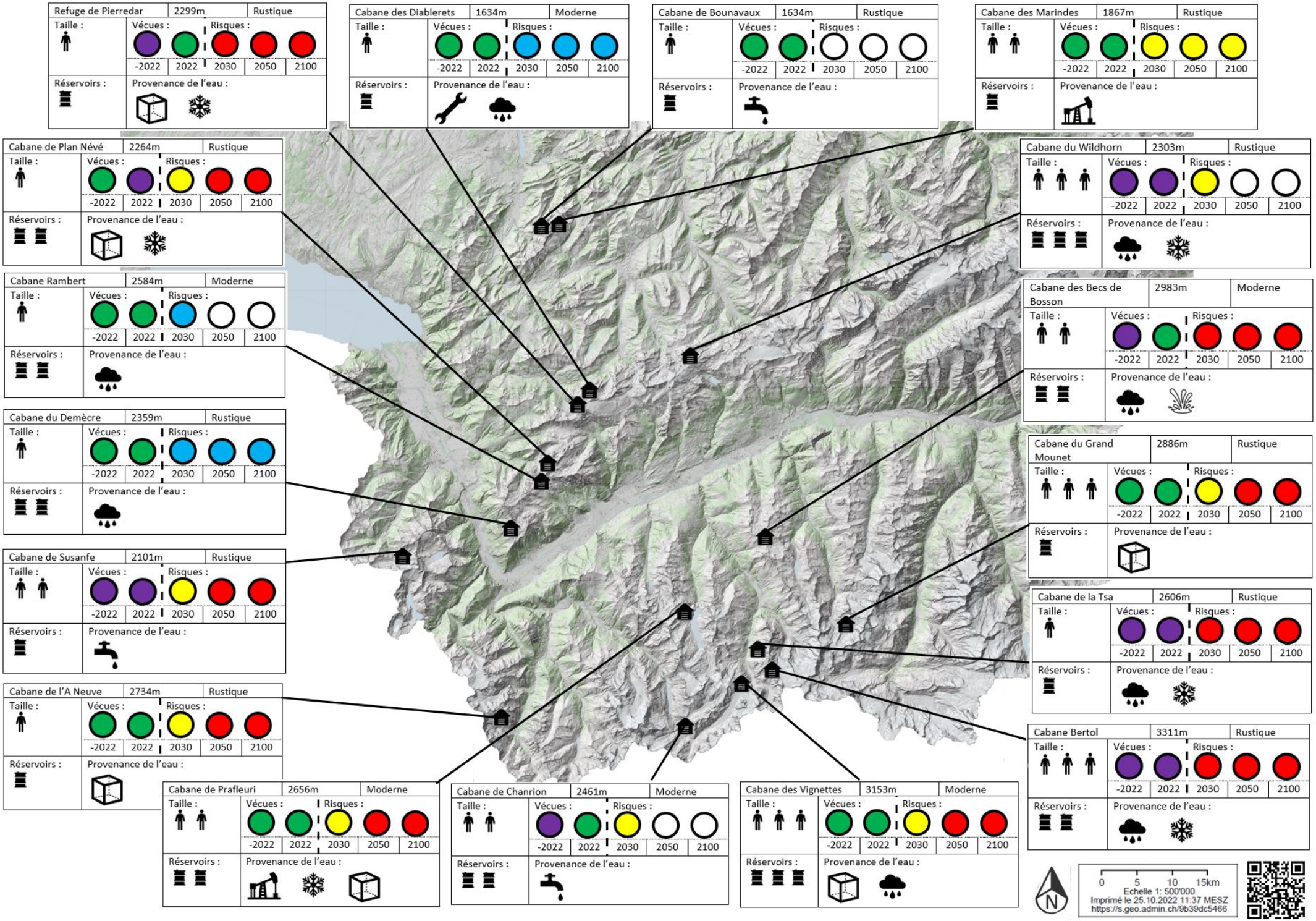

Figure 2 : Map showing access to water and the characteristics of 17 huts in French-speaking Switzerland. Legend in figure 1

3. RESULTS AND INTERPRETATION

In order to analyse and interpret the data with some structure, the huts were considered, firstly, according to their method of water supply, and then according to their modernity.

3.1. Capture of meltwater from eternal snow

Up to now, the huts that draw water from the melting glaciers have not suffered any water supply problems, apart from the Plan Névé hut and the Pierredar refuge. In fact, every summer, the glaciers melt and release large volumes of water, as they did in the summer of 2022, which can supply the huts. However, this retreat has had an impact on the water supply system in some of the huts, such as Plan Névé, where the guardian has had to move the catchment area every day to follow the glacier's movements and ensure that the water flows. The managers of the Pierredar hut above Les Diablerets exclaim: 'It's paradoxical: because of the high temperatures in the summer of 2022, the glacier supplying us with water melted more than usual, so the water flowed in profusion. In the long term, this is obviously very bad'. The same applies to the Grand Mountet and Les Vignettes cabins, whose operators both point out that the glaciers are melting, releasing large quantities of water that can be used in their establishments.

However, the interviewed guardians predicted a high risk of water shortages in the coming years. If glaciers continue to retreat at this rate because of rising temperatures, they could virtually disappear by 2100 (Rounce et al. 2023). These huts will no longer be able to exploit this water resource. It should also be noted that huts with a catchment on a small glacier at low altitude are more exposed to water shortages because of a smaller volume of ice and higher summer temperatures.

3.2. Capture of meltwater from eternal snow

The huts collecting water from the melting firn all experienced supply problems over the last years, with the exception of Prafleuri, which benefits from the infrastructure of the Grande Dixence dam. For the summer of 2022, these difficulties can be explained by the weak snow cover established during the winter (Pielmeier & Heggli 2022) – "*only 70 to 90% of the 1991-2020 norm fell*" reports MétéoSuisse (MétéoSuisse 2022) - combined with the high summer temperatures. These snowdrifts, which were less voluminous than in previous years, melted rapidly as soon as winter ended. Water flowed during the first days of opening, filling the hut reservoirs. Once the tanks were full, the water could no longer be stored and was lost. This created complications for the cabins, as their primary source of supply dried up at the start of the summer season. What's more, this source of supply is

dependent on winter and summer weather conditions. If the winter is poor in snow and the summer is hot, the amount of water provided by melting snow will be small and of limited duration. The guardians would prefer the opposite: a winter rich in snow and a summer with low temperatures, in order to benefit from a greater availability of water, both in terms of duration and quantity.

In general, the guardians are pessimistic about the future of the snow. They fear that a similar episode will occur again in years to come. Fortunately, these huts also collect rainwater so that they can cope with shortages and remain open.

3.3. Collecting rainwater

Most of the huts use rainwater harvesting as a complement to another source of supply, such as glacier meltwater or eternal snow. Only two of the huts surveyed, located close to each other as can be seen on the map - the Rambert and Demècre huts - rely solely on rainwater for their supplies. The reason for this single source of supply is the geographical location of these huts. Neither glacier nor firn can provide their meltwater in the vicinity of their sites (Vandermassen 2016). What's more, the soil in this region is karstic in nature, allowing rainfall to infiltrate rapidly into the subsoil. The water then joins the groundwater, which flows rapidly downstream, offering no possibility of pumping (Brühlmann et al. 2004). The reservoirs in these huts are larger than their capacity. Their strategy for avoiding water shortages is to store as much rainwater as possible during wet spells to ensure that it is available during periods of drought (Vandermassen 2016). So far, they have not experienced any critical episodes.

The guardians are confident about the future. Does the fact that they cannot obtain water by any other method play a part in their judgement? In the future, the frequency of rainfall will become less frequent, while the intensity of rainfall will be greater. Will they still be able to rely on their reservoirs? Will they need to be enlarged? These questions remain open for the time being.

3.4. Pumping from an aquifer

There are three types of aquifers, depending on the characteristics of the underground - loose, karstic or fissured. Each aquifer has its own characteristics, such as storage capacity and water flow velocity (Brühlmann et al. 2004).

To obtain their water supply, the cabins simply need to pump water from underground. However, these establishments are as dependent on the hydrological characteristics of the aquifer

as they are on the winter and summer rainfall that feeds the aquifer. Depending on the size of the aquifer, a winter with little snow and a dry summer will not be able to fill this natural reservoir. What's more, especially in karstic aquifers, the water can quickly flow downstream and no longer be available for the huts. An aquifer in loose rock would be an advantage in this respect thanks to its low flow velocity (Brühlmann et al. 2004).

The Marindes hut, located at the foot of the Vanil Noir, on limestone rocks forming a karstic aquifer (Vonlanthen 2019), obtains its water in this way. To date, it has not suffered any water shortages.

3.5. Capture of spring water

A spring is defined as the place where water naturally gushes out of the ground (Water Science School 2019). Springs have the same characteristics as aquifers because their water is defined as groundwater (Brühlmann et al. 2004). However, they offer the advantage that pumping is not necessary as long as they are located upstream from the point of consumption.

Huts that collect water from a spring are therefore also dependent on summer and winter weather conditions. If annual rainfall is low, the aquifers can dry up, as well as the spring. The guardian of the Susanfe hut, located on karstic ground at the foot of the Dents du Midi, has experienced this situation on several occasions, particularly during the particularly dry summer of 2022. In the Fribourg Pre-Alps, at the foot of the Vanil Noir, the Bounavaux hut also lies on karstic ground (Swisstopo, 2022) but has never seen its source depleted. The hypothesis of a larger aquifer at Bounavaux than at Susanfe would explain why the Bounavaux spring has never run dry. Water availability is greater at Bounavaux than at Susanfe.

For the future, Susanfe's guardian believes that the situation will become critical, particularly with the rainfall spacing out. She wants to renovate her hut and install larger reservoirs. The operators of the Bounavaux hut are not making any predictions about the future of its water supply.

3.6. Pumping from a lake

The Becs de Bosson hut, located on a ridge, is the only hut we interviewed that obtains its water from a lake. There are no glaciers in the region and the snow does not last throughout the season. Nevertheless, there are three small lakes below the hut. At the start of the season, they collect the meltwater from the firn and then, during the summer, they collect the run-off from the

precipitation on the mountainside. The hut has invested in a pumping system to bring the water up to its reservoirs from 140 metres of positive vertical drop. Before 2022, it suffered water shortages due to a fault in the system. However, the system has now been renovated, and the summer of 2022 passed off without a hitch despite the drought, as the hut's guardians said.

The guardians' predictions for the future are pessimistic. Apart from the dependence on winter and summer rainfall, temperatures are affecting the sustainability of its water supply system by modifying the evaporation of water bodies. According to the FOEN's Hydro-CH2018 research project, hydrological scenarios show a 10% increase in average evaporation by the end of the century, resulting in the loss of one millimetre of water per day during the summer, without any measures to fight global warming (Schmocker-Fackel et al. 2021). Ultimately, this will lead to a drying up of the soil and water bodies. Depending on climatic conditions, the hut will no longer be able to pump water from its lakes if they dry up.

3.7. Comparing rustic and modern

Through this survey, the guardians were asked to assess the modernity of their hut without any pre-set criteria. This notion provides indirect information on the level of comfort offered to guests: access to sanitary facilities, showers or drinking water. It also indicates the state of the infrastructure: a recent renovation, the presence of a dishwasher or whether the pipes are in good condition. In a so-called modern hut, customers expect a higher level of comfort that may require the use of more water than in a rustic hut. Modern establishments can therefore be expected to be more exposed to the risk of water shortages due to higher water consumption.

Eleven guardians rated their establishments as rustic, while only six described them as modern. Of these 11 rustic cabins, 6, i.e. more than half, had experienced water shortages. These 6 huts obtain their water either by collecting water from melting ice (2 huts), water from melting eternal snow (3 huts) or water from a spring (1 hut). On the other hand, only 2 so-called modern huts, i.e. a third, experienced shortages. One, the Chanrion hut, draws water from a spring and the other, the Becs de Bosson hut, pumps water from a lake. On the basis of this observation, the hypothesis of a higher risk of shortage for the modern cabins can be dismissed.

It's true that water consumption can be higher but, as mentioned, modernity can also improve the hut's infrastructure, making it less water-intensive or more efficient. The Becs de Bosson hut is a good example of this (see point 3.6.). In addition, following a renovation, a hut's water supply system

is rethought and adapted to its needs. The Chanrion hut is a good example. Its renovation enabled the location of its water catchment to be changed, so that it can now avoid water shortages.

The rustic huts have not seen their supply system evolve over time, although climate change is altering the Alps. Although rustic huts offer less comfort, their facilities are ageing and no longer meet their needs. The volume of water available to the huts that collect water from melting snow is decreasing over the years (see point 3.2.), while their consumption remains the same. The spring at the Susanfe hut has dried up. This may be due to changes in rainfall patterns. Its supply system is no longer suited to its needs. The Pierredar refuge and the Plan Névé hut, which get their water from glacier melt, explained that their shortages were due to technical problems with their ageing installations. Some of their pipes were blocked or their catchment grids were obstructed.

In conclusion, modern cabins are more able to avoid shortages than rustic cabins. They are more comfortable, but their facilities are appropriate to the current climate and their needs. Conversely, the infrastructure and supply systems of rustic huts have become inadequate to cope with climate change and their consumption levels. Is modernising huts the solution to the shortages?

4. CASE STUDY: BERTOL HUT

The first part of this study shows that the water supply situation is not widespread. Consequently, the following chapter about a particular hut is necessary to understand the real issues and challenges these alpine establishments are facing in terms of their water supply. Having worked at the Bertol hut for 3 months, I chose it for this analysis.

4.1 General information about the hut

In 1888, the need for a hut on the Col de Bertol became obvious to the Swiss Alpine Club. The pass, which links the Val d'Arolla with the Val de Ferpècle, has always been a popular route for mountaineers, who now take the Haute Route between Chamonix and Zermatt or the famous Patrouille des Glaciers race. At the time, the Col de Bertol was covered in ice, so it was decided to balance this building on a buttress of the Bertol bell

Figure 3 : The Bertol hut, in the centre of the image, on its rocky outcrop. The bell tower of the hut, also known as the Bertol bell tower, on the left, and the Bertol pass on the right. In the background, Tête Blanche (Source: Photo by Stéphane Schenk)

tower (fig. 3), offering a magnificent panoramic view of the Dent Blanche, the Matterhorn, the Dent d'Hérens, the Mont-Miné glacier and the Ferpècle glacier (Jeanneret, 1926).

The hut was completely rebuilt in 1972 to the plans of Zurich architect Jackob Eschenmoser, who came up with the idea of creating a polygonal tower with 4 levels, optimising the number of beds and reducing the footprint. In 1980, the Swiss Alpine Club granted a loan of 55,000 Swiss francs to find a permanent solution for the water supply (Monin, 2001). Since then, the hut, which can accommodate 80 people per night, has changed very little. Solar panels, installed on the roof and linked to batteries, are enough to supply the hut with electricity. The helicopter is used to transport food and waste down to the valley. The sanitary facilities, located in a small annex for reasons of space, consist solely of dry toilets. Urine is discharged into the environment, while excrement is stored in sawdust bags and then removed by helicopter.

The climatic situation at the Bertol hut is based on measured data from MeteoSwiss combined with the COSMO digital model (MeteoSwiss, 2023b). Given its altitude of 3311 metres, the Bertol hut is exposed to relatively low temperatures throughout the year, with the norm fluctuating between -12.2°C and -10.1°C in January, February and March and between 3.4°C and 5.2°C in June, July and August. However, as temperatures rise, this norm should evolve towards higher temperatures, which would have an impact on the form of precipitation - snow or rain - as well as the rate at which snow, ice and permafrost melt. The difference between the winter precipitation norm (67 mm to 78.8 mm in January, February and March) and the summer precipitation norm (114.2 mm to 122.1 mm in June, July and August) can be explained by the increase in stormy weather bringing large quantities of water. However, MeteoSwiss has observed an increase in liquid winter precipitation and a decrease in snowfall, thus affecting the formation of snowdrifts, an important source of water for the huts (MeteoSwiss, 2023c). It should be noted that due to its geographical location, the hut is subject to strong gusts of wind, which are not measured by MétéoSuisse.

4.2 Access to water resources

"*To finish its season, the Bertol hut has to be very careful about its water consumption if the weather conditions are not favourable - little rainfall and high temperatures - as was the case during the summer of 2003, or more recently, the summer of 2022*" explains hut guardian Stéphane Schenk. The hut faces a paradox. It's surrounded by glaciers, it has water in solid form, but it lacks it. The main reason for this absence is that the hut is located 50 metres higher than all this water, which is

currently abundant. The hut has therefore set up two systems to guarantee the water supply during the summer period:

1. Firstly, the hut collects the rainwater that falls on its roof. Despite its 100m2 roof, this method is not very effective given the strong wind gusts that sweep the rain over its roof. What's more, this method is totally dependent on rainfall. If it doesn't rain, no water ends up in the hut's reservoirs.
2. The hut therefore supplements its water supply by collecting meltwater from a firn on the south face of the Pointe de Bertol (fig.5B). Due to its south-facing position, the sun causes the water to melt quickly, as does the permafrost thawing on the rock face, leading to rock falls. These rockfalls can damage the 300m-long pipe linking the catchment to the hut (fig.5D) or even block the catchment grill (fig.5C). The maintenance of this installation is very complicated and requires specialist mountain guides to ensure safety. Once again, this supply system is dependent on winter weather conditions, for the accumulation of snow and the formation of firn, and summer weather conditions for its melting or potential snowfalls (due to the altitude) regenerating the firn and the run-off of rainwater on the rock face. Rising temperatures will accelerate the melting of the firn and increase the number of rockfalls, which could damage the infrastructure.
3. To guarantee the availability of water, the Bertol hut has a storage capacity of 18,000 litres of water spread over three areas of the hut, acting as a buffer between consumption and supply.
4. Zone 1, located under the kitchen, collects water from the catchment and the rectangular roof, which is then redirected to zone 2 (purple pipe in fig.4) when it is full. Zone 2 is fed by the overflow from zone 1 and the water from the octagonal roof. When it is full, the water is either lost because all the hut's reservoirs are full (brown pipe on fig.4), or pumped to fill zone 1 (purple pipe on fig.4). Zone 1, by means of a pump, also distributes water to zone 3 (pink pipe on fig.4) located above the kitchen in order to create pressure for the only tap in the hut (red pipe on fig.4) which is located in the kitchen (fig.4). Both pumps are manually operated by the hut's guardian, who is then responsible for water management (Schenk).

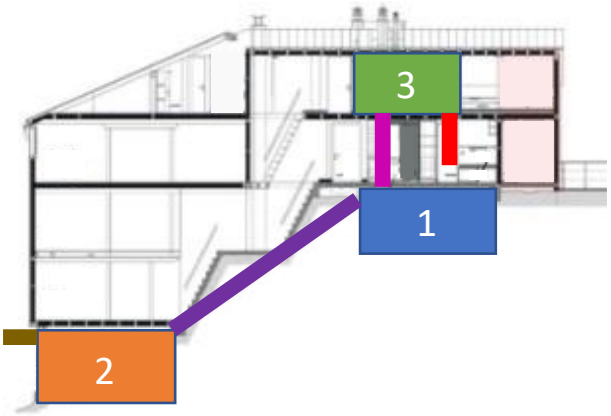

Figure 4 : Schematics of the hut's tanks (Source of background image: CAS construction guide).

However, the buffer role is only optimal to a certain extent because of the weather conditions. A warm start to the season causes the firn to melt quickly, filling the reservoirs which,

once full, can no longer store the excess of water. As a result, poor management can lead to water shortages at the end of the season despite an initial abundance, as in 2022 when the firn had melted completely by July. Fortunately, a few rainy spells in August filled the reservoirs and ensured the end of the season (Schenk, pers. com.).

4.3 Current and future solutions to avoid water shortages

The Bertol hut has to be constantly mindful of its water reserves. "*Even if the reservoirs are full and there's rain in the forecast, that's no reason to run the water while washing up.*" exclaims Stéphane Schenk. As previously seen, long-term management is needed to avoid water shortages. In addition to the guardians' ability to manage water, they are implementing several small solutions to save water. The use of water is restricted to the strict minimum and access to it is limited. Dry toilets also reinforce their efforts to save water. In the event of a water shortage, Stéphane Schenk has only one solution: closing down. "*Supplying water by helicopter is not viable in the long term. It's only a stop-gap solution if we run out of water and they forecast rain in two days'time*." he says.

The predictions for the future are quite bad. The hut is already isolated and has a low water supply. Jean-Marc Schouller, the hut's attendant, exclaimed in RTS's Vacarme programme: "*It would be ridiculous to think... it's melting and we can't do anything about it. No, it's melting, we need to find other solutions*" (Glacier 3/5 - cabane en équilibre, 2021). These other solutions are not numerous. Here are just a few:

- The simplest, cheapest and quickest solution would be to enlarge the reservoirs. However, the hut is already cramped on a rocky outcrop, and this solution would not guarantee a constant supply. The hut would remain dependent on current water resources. However, this idea would have the effect of improving water management (buffer effect).
- A second solution would be to extend the catchment pipe to the Aiguille glacier behind the Pointe de Bertol, in the direction of the Aiguille de la Tsa (Fig. 5A). This idea is, however, vulnerable due to rock falls and complicated maintenance.
- A third solution would be to resolve the Bertol paradox. It would be possible to pump water from the Mont-Miné or Bertol glacier, both located 50 metres below the hut. This system would require a complex infrastructure with a pump that, according to Stéphane Schenk, would consume far too much electricity compared to its daily output. However, he still has this solution in mind, because with technical progress, a pump that consumes less electricity might still come onto the market.

- Inspired by work carried out by the Pontificia Universidad Catolica de Chile and the Canadian NGO FogQuest, a fourth solution could be put in place. Since 1998, researchers in the Atacama Desert have been taking their inspiration from plants, which are able to capture water particles in the air, to develop a new water supply method consisting of harvesting the water naturally present in the clouds using vertically positioned nets. According to their calculations, in the Atacama Desert, at Alto Pataches, one square metre of net provides an annual average of 8 litres of water per day. For once, the topography of the Bertol hut's surroundings would be an advantage. As mentioned earlier, the hut is located next to a pass where the clouds gather, trapped by the surrounding peaks, and where the winds blow hard. To discern the potential of such an installation at Bertol, the local climatic conditions would have to be studied over many years. In addition, this method is inexpensive and easy to install (LowTech 2020). In any case, its feasibility needs to be verified at this altitude, particularly in view of the low temperatures, which can cause frost even in summer, and the strong wind gusts that can rip the nets off.
- There is one more important point. Compared with other Swiss Alpine Club huts, the water supply capacity of the Bertol hut is low in relation to its size. The more people a hut welcomes, the more water it has to consume to satisfy the needs of its clientele. The Bertol hut is one of the large huts interviewed during this survey, along with the Vignettes, Wildhorn and Grand Mountet huts. Only Bertol and Wildhorn, both of which are fed by snowmelt and rainwater, have had problems with their water supply in recent years. In order to save water, these huts could reduce their capacity per night during critical periods, as the Bertol hut does. Significant quantities of water would then be conserved, bearing in mind that for every 10 overnight stays, it consumes approximately 75 litres of water, according to the guardians' calculations. The Bertol hut is a laboratory on the subject of water management. If the other cabins with water supply problems were to take inspiration from this idea of reducing the number of guests, they could have a smoother summer season, even if this solution reduces the financial benefits.

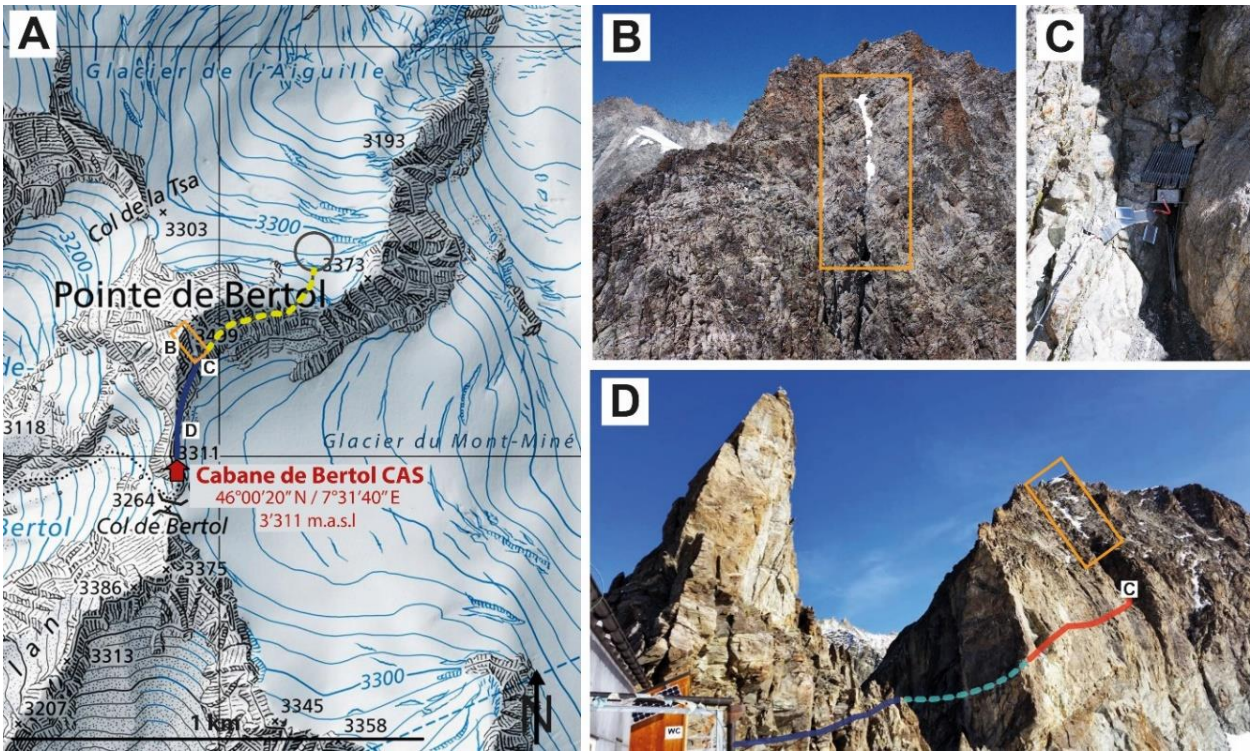

Figure 5 : A: Location of water supply equipment (blue line) at Bertol mountain hut (Valais). The yellow dotted line indicates the proposed extension of the water pipe to the aiguille glacier (grey circle) (source: swisstopo). B: South face of Bertol peak with the snow accumulation zone supplying the hut's water catchment (July 2022). C: Water catchment grid. D: Water pipe linking the hut to the water catchment. The light blue dotted line indicates the overhead section of the pipe (60 metres), the red line section that is highly exposed to rockfalls and difficult to access (photos: Stéphane Schenk)

5. CONCLUSION ET DISCUSSION

To conclude, let's return to the hypotheses set out in the introduction.

- The first hypothesis, “huts fed by meltwater from eternal snow are more likely to suffer water shortages than those fed by glacier meltwater”, is confirmed by the study. All the huts fed by glacier meltwater have experienced no water shortages in recent years, as has the Prafleuri hut. As temperatures rise, the water stored in the ice is transformed into a liquid resource. Water is flowing in large quantities. Nevertheless, these huts need to be careful about their future, as the glaciers are melting and losing volume. When they are gone, the water will no longer flow, and the huts will have to find other means of supply. On the other hand, this rise in temperature does not benefit the huts that collect water from the melting snow. The firn is thinner and melts as soon as winter leaves. These huts, like the one at Bertol, are therefore finding it difficult to finish the summer caretaking season.
- The second hypothesis is not validated by this study. Admittedly, the capacity of a hut has an impact on its water consumption, but a shortage depends more on the water supply system. A hut, whether large or small, must have a supply system sized according to its needs in order to

guarantee water availability. This assumption is made on a case-by-case basis, as demonstrated by the comparison between the Vignettes and Bertol huts, which are the same size but have different supply systems.

- This analysis does not support the third hypothesis, which is that huts with a single spring have difficulty obtaining water. Once again, this is a case-by-case situation, which is highlighted by the comparison between Susanfe and Bounavaux. If their only source is abundant and their water management is optimal, there are no problems, as in Bounavaux. On the other hand, Susanfe has a low-flow spring and small reservoirs regarding its size, which may explain its difficulties.
- The fourth hypothesis is partially confirmed. Owning large reservoirs is no guarantee of avoiding a shortage, but it does provide appreciable help. Reservoirs are invaluable tools for water management. They enable water to be stored and made available at any time. They act as a buffer between consumption and supply. However, they must first be filled. This action depends on the supply system used by the hut.
- The last hypothesis is confirmed by the study. Despite greater comfort, which may mean greater water consumption, modern cabins are more able to avoid water shortages than so-called rustic cabins, because their supply systems are adapted to the current climatic situation and sized according to their needs. On the other hand, the facilities in rustic cabins have not evolved in response to climate change, which means that they are no longer able to meet their needs adequately. So the question arises: is modernising the huts the solution to shortages?

Overall, the water supply situation for mountain huts during the summer period is a case-by-case matter and depends on three factors in particular:

1 The geographical location of the hut
2 The water supply system
3 Water management within the establishment

With current climate trends, most guardians are concerned about the sustainability of their establishment. In the future, reservoirs will be needed to overcome periods of drought caused by irregular rainfall and to collect as much water as possible from intense rainfall. Water management, as practised at the Bertol hut, will have to be applied to the other mountain huts. Rising temperatures will make it necessary to relocate some water catchments, extend pipes or secure infrastructures against rockfalls. In short, the guardians, with the help of the Swiss Alpine Club, will have to find and

invest in solutions specific to each situation to guarantee the availability of water in their hut and thus avoid closing down.

Global warming poses a challenge not only in terms of water supply, but also in terms of the safety of certain huts. By changing weather patterns, global warming is increasing natural risks such as rockfalls caused by melting permafrost. These rockfalls have a direct impact on the huts, damaging their structures and also indirectly blocking their access ways. In short, global warming is impacting mountain environments in their entirety, posing a number of challenges for all mountain establishments: water, but also safety. As a result, mountain huts must constantly evolve and adapt to these challenges to ensure their long-term survival.

In addition, the problem described in this work can be generalised on a global scale for two reasons. Firstly, global warming is not a phenomenon isolated to the Alps, but affects all regions of the planet, regardless of their morphology. As a result, the climate in each region is tending towards a change that could have an impact on water resources. Secondly, Swiss huts are not the only structures in the world that need to be supplied with water. In fact, any structure offering accommodation to humans (hotels, accommodation centres, etc.) requires a water supply to meet the basic needs of their guests. From these two points, it follows that the issue of water supply will become central and will concern the entire world population. Lima, the capital of Peru, is already facing complications in guaranteeing water availability (Chaparro 2024), while the South Asian region will encounter similar difficulties by 2050 (Albinia 2020). The relevance of this work is therefore not insignificant, as it highlights a major future global problem, starting from a local scale. The study of the water supply situation in the Swiss huts in French-speaking Switzerland, with its particular and specific cases, is new and unprecedented. Nevertheless, it reflects a wide-ranging problem, while facilitating understanding and raising awareness among the general public by showing its causes, the issues at stake and possible solutions. The study of a particular case is presented here as an educational approach to explaining and demonstrating a complex and far-reaching problem. This work is therefore as interesting for the guardians of the huts as it is for the world's population, who in the future will have to face the same challenge: guaranteeing the availability of water. It is interesting to note that this challenge is included in the UN's list of sustainable development goals. This work therefore highlights an objective defended by a global organisation.

Finally, it's important not to forget that the Alps run through several European countries: Switzerland, Germany, Austria, France, Italy, Liechtenstein, Monaco and Slovenia. Although these

countries are separated by political borders, they all share the same natural environment: the Alps. As in Switzerland, there are also mountain huts in France and Italy, which will face similar challenges when it comes to their water supply. It would therefore be interesting to consider international cooperation, initially in Europe, on the supply of water to mountain huts. I would suggest, for example, setting up an internet platform where guardians from different mountain huts in the Alps could share their problems and the solutions they have found. This internet platform would be a way of putting aside political boundaries to find effective solutions together. It would also enable local experiences to be brought together to find global, cross-border solutions. Cooperation is a key element since the problem of water supply concerns us all: it does not stop at the limits drawn by political borders, which are not environmental borders.

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