The Impact of Urbanization, Industrial, Agricultural and Forest Technologies on the Natural Environment

Edited by Miklós Neményi and Bálint Heil

NEW SZÉCHENYI PLAN

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Water Use Management in Dry Mountains of Switzerland. The Case of Crans-Montana-Sierre Area

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Abstract – Crans-Montana-Sierre is an Alpine tourist region located in the driest part of Switzerland. This paper presents preliminary results from the MontanAqua project (www.montanaqua.ch), which aims at developing more sustainable water management options based on the coordination and adaptation of water demand to water availability under changing biophysical and socio-economic conditions. The focus is upon the temporal and spatial characteristics of resource demand, in order to estimate the spatial footprint of water use (drinking water, hydropower production, irrigation and artificial snowmaking). A large summer peak and a smaller winter peak characterize current regional water consumption. The summer peak is primarily caused by irrigation demand but secondly by drinking water demand. The winter peak is essentially due to drinking water demand and snowmaking demand. The results show the difficulty of collecting homogenous data on water usage due to a lack of data and measurement systems.

Keywords: water management, water uses, tourism, mountain areas, Swiss Alps

Introduction

Water resources are of central importance to the prosperity and development of a society. However, climate change and socio-economic changes are leading to pronounced changes in both water supply and water consumption especially in critical areas like dry regions and/or areas with fast economic and demographic growth. The Alps are commonly considered as the water tower of Europe (Viviroli – Weingartner 2004) and so we might conclude that there are no major issues concerned with future Alpine water. Nevertheless, inner alpine dry valleys such as the Rhône (Switzerland), Inntal (Austria), or Adige and Aosta (Italy) could find themselves under stress in the future.

Water distribution in Alpine regions takes place today mostly at the commune level. Until now, in most areas, water managers assumed that water supply was more or less constant and sufficient to satisfy all use needs. As a result, water management focused on distributing sufficient water according to water demand (water supply management) and few attempts have been made to adapt water usage to resource scarcity (water demand management). Even if at the moment one cannot consider that Switzerland or the Alps in general are in water stress, climatically driven water shortages associated with increasing water demand could cause problems for water distribution in the future (European Environmental Agency 2009, Alp-Water-Scarce 2011) and climate change and associated hydrological changes (Bundesamt für Umwelt BAFU 2012) will impact on several water uses (OcCC – Proclim 2007) such as hydropower production (Société suisse d'hydrologie et de limnologie – Commission d'hydrologie 2011) and irrigation (Fuhrer 2010). It is, therefore, important to be able to model future water availability (e.g. Alcamo et al. 2007) and water demand (e.g. OECD 2012) and the management systems (e.g. Ernst Basler et al. 2007) that need to be developed.

That is the main objective of the national research programme NRP 61 Sustainable Water Management (www.nfp61.ch). The programme aims (1) to develop scientific foundations, methods, and strategies and to discuss solutions for future challenges in the area of water resources management, (2) to investigate the effects of climate and social changes on water resources, (3) to examine risk management and use conflicts from a comprehensive perspective, and (4) to develop efficient and sustainable water resources management systems (SNSF 2008). The programme has a natural system axis and a social system axis and some projects present an interdisciplinary character. That is the case for the project *MontanAqua – Approaching Water Stress in the Alps. Water Management Options in the Crans-Montana-Sierre Region (Valais)* (Weingartner et al. 2010), from which the research presented in this paper is a part.

Objectives of the MontanAqua project

The MontanAqua project is an interdisciplinary project carried out by the institutes of geography of the universities of Bern, Fribourg and Lausanne. In close collaboration with local authorities and stakeholders, the project aims at developing the solutions required for a more sustainable and balanced management and distribution of water in the Crans-Montana-Sierre region (Canton of Valais, Switzerland) (Figure 1). The spatial extent is the territory of 11 local municipalities and both the current (around 2010) and future situation (around 2050) are analysed and modelled. This study area was chosen because it is the driest part of Switzerland and it has faced rapid demographic growth and fast development of tourism during the last decades.

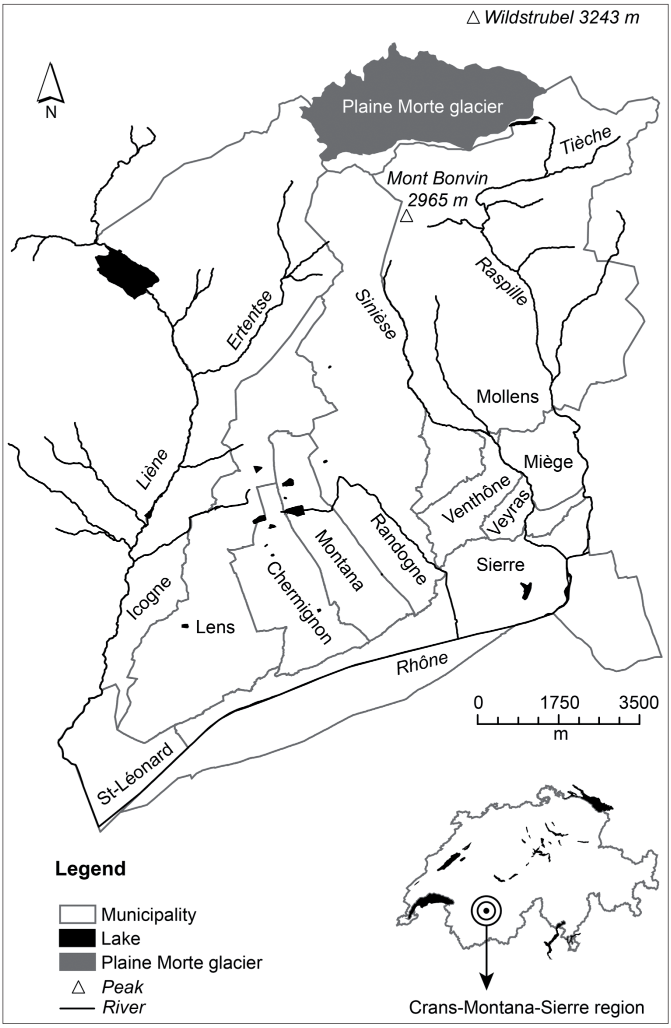

FIGURE 1. Situation of the study area

Specific goals of the project are (Figure 2) (WEINGARTNER et al. 2010):

– the evaluation of present and future availability of water in the study area (work-package 1 – WP1);
– the evaluation of water use by different user groups and the assessment of future water use, taking into consideration societal and economic changes (WP2);
– the evaluation of the existing legal and practical organization of water management and the development of options for more effective water management (WP3).

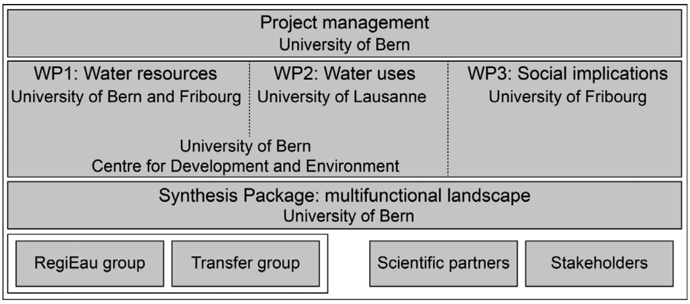

FIGURE 2. Structure of the project MontanAqua

The results of the three workpackages are collected and analysed in an interdisciplinary way in a synthesis package (SP) and the overall aim of the project is to develop options for optimal distribution and management of water resources together with the stakeholders involved and to give recommendations to local political authorities, land planners, and several stakeholders dealing with water issues. Thus, local and regional actors are involved in a dialogue about what might constitute optimal management within a working group with actors from the communes and the region (RegiEau group, Figure 2). This working group is particularly active in the definition of socio-economic scenarios. Indeed, future water demand modelling needs information about both climate and socio-economic scenarios. For climate scenarios, we based our analysis on the recently published Swiss climate change scenarios (CH2011 2011). For socio-economic scenarios, the challenge was to find realistic data concerning the study area in the years 2040-2050 and not only general scenarios elaborated at country level. Nevertheless, these kinds of regional scenarios are not available at the moment. That is one reason for the creation of the RegiEau group. The stakeholders involved, who represent local and regional political authorities and administrations, economic stakeholders, and non-governmental organizations, were asked to elaborate visions for their jurisdiction for the middle of the 21st century. A first meeting was organized in June 2011 and brainstorming allowed us to identify possibilities for the future of the study area in the opinions of various stakeholders. From this, the MontanAqua team elaborated three different scenarios characterized according to various themes (demography, water consumption, land-planning, tourism, agriculture, etc.); the first one is a scenario aimed at economic growth in the area (more tourism, more production of energy, etc.), the second is a scenario of optimization of the current economic pattern, and the last one is a scenario of economic decay (demographic decay, development of soft tourism, etc.). The group of stakeholders finally decided to elaborate a fourth scenario (situated between optimization and decay), characterized in particular by the strong reduction of house building, the conversion of tourism, the optimization of agriculture, etc.

A second support group – called Transfer-group (Figure 2) – is composed of people dealing with water scarcity issues in other parts of the Alps. The aim of this group is to help the MontanAqua team to disseminate results in other parts of the Alps concerned with water issues.

In this paper, we focus on the water use issues (WP 2). The objectives of this work-package are (Figure 3): (1) to characterize and describe the water use system at the scale of the study area; (2) to study in more detail the principal water uses in the area, by describing the infrastructures and the organizational structures; (3) to quantify the water volumes used by the different water sectors at the municipal spatial scale and at the monthly temporal scale; (4) to characterize the overall water management on a regional scale in terms of water use and demand and to compare the current water volumes used with the resource availability (calculated by WP 1); (5) from this, to model water needs in 2050; (6) to elaborate recommendations for the local authorities. In this paper we focus on the first part of the study, which is the description of the water use infrastructures and organization, as well as the quantification of volumes currently used.

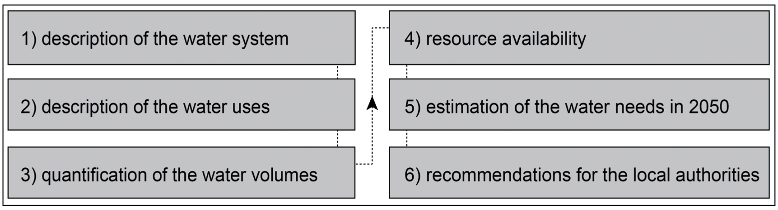

FIGURE 3. Steps of the WP 2 research

The study area: the tourist region of Crans-Montana-Sierre

The region of Crans-Montana-Sierre is situated on the right side of the Rhône River, in the central part of the Canton of Valais, Southwestern Switzerland (Figure 1). Altitudes range from 530 m ASL on the Rhone River plain to 3243 m ASL. Climate is characterized by quite high mean temperatures in the Rhone valley (mean temperature (1980-2009) in Sion (482 m ASL), situated 10 km west of Sierre, is 10 °C) and cooler temperatures at higher elevations (annual mean in Montana (1423 m ASL) is 5.8 °C for the same period) (Figure 4). Annual rainfall is less than 700 mm in the Rhône River valley (608 mm in Sion and 678 mm in Sierre during the period 1980-2009) (Figure 4). Rainfall gradients are high (996 mm in Montana (Figure 4); more than 3000 mm in the Tseuzier area (see location on Figure 1). The region cannot be considered as an arid area in absolute terms but rainfall in general is not uniformly distributed over the territory.

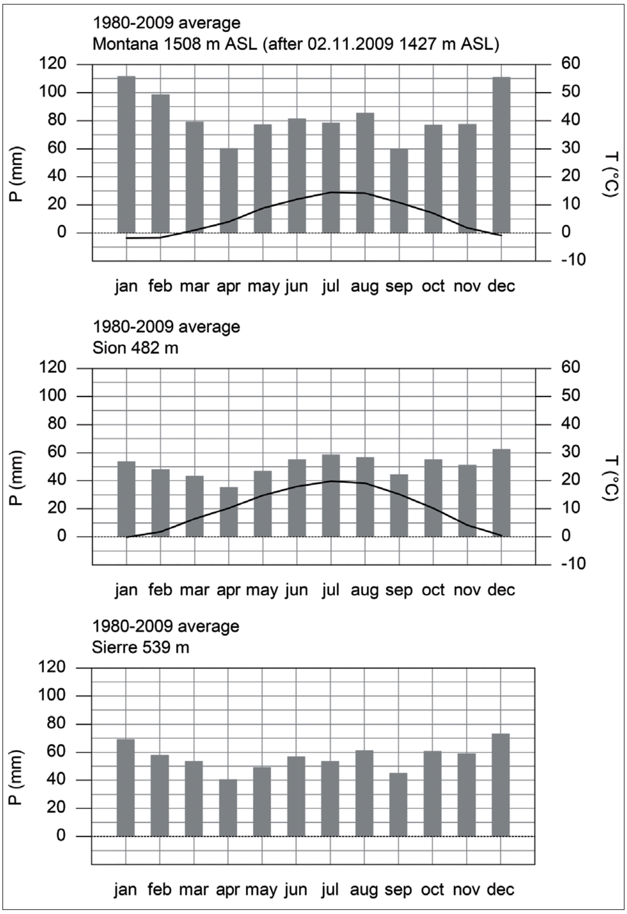

FIGURE 4. Climatic data in the study area

Hydrology is characterized by the presence of two main catchments, the Raspille River catchment and the Liène River catchment, respectively in the eastern and western part of the area (Figure 1). The Liène River was dammed in 1957 for hydropower production and the artificial lake of Tseuzier allows 51 million cubic metres to be stored. Because of complex use rights established in 1490, the Raspille River could not be dammed for hydropower production (Reynard 2000a). The hydrological regime of the Liène River is b-glacio-nival (following Aschwanden – Weingartner 1985) in the upper course and nivo-glacial in the lower course. The Raspille River has a "nival alpin" regime. Several small rivers with a nival hydrological regime drain the area situated between these two catchments. Moreover, karstic features and processes characterize the upper part of the catchments (Wildberger 1981). It means that a substantial proportion of the runoff is underground and catchment karstic water transfers are an important feature of the regional water resource.

A glacier (Plaine Morte Glacier; surface 8.42 km^2; volume 0.92 km^3; data: Matthias Huss, University of Fribourg) is located in the upper part of the region (Figure 1), in the karstic area; most of the meltwater flows underground to the North, out of the studied area. Because of its location in a depression, the glacier is retreating rapidly and could disappear by 2080.

The regional economy is based mainly on three main sectors: agriculture (in particular viticulture); industry (aluminium factories in Sierre); and tourism (in Crans-Montana). Agriculture has been intensively practised since the Middle Ages, and was intensified by recourse to irrigation in the 14th century. Until the first decades of the 20th century, it was mainly multiple-crop agriculture, practised at the family scale, with three major types of crops: vineyards at the lower elevations, in particular in difficult terrain; cereals (and other crops such as orchards, potatoes, etc.) on the hillside (below 1000 m ASL), and irrigated meadows and non-irrigated pastures at higher elevations. Part of the production was consumed by the family and part was sold, and a complex system of seasonal migration was developed to maximize economic performance of the system (Girardin – Bruhnes, 1906).

During the last decades of the 19th century, three profound economic changes transformed this economy. In 1860, the construction of a railway line to Sion allowed the import of cereals from abroad, cheaper than local ones, provoking the progressive decay of local cereal production and initiating a process of concentration and specialization in agriculture. This tendency was accelerated in the decades following the Second World War, when large areas were transformed into vineyards (Reynard et al. 2007). The second change was the development of chemical and metallurgical industries along the Swiss Rhone River, because of the presence of hydroelectric energy. This prompted the status of the so-called "worker-farmer", that is people working 8 hours at the factory but continuing, with the help of the family, the farming activity. This organization is still partly in use, especially in the vineyard sector. The third change was the development of tourism. In 1892, a first hotel was built in the so-called "Haut-Plateau", and rapidly Montana became famous for medical tourism (TP treatment); in the first decades of the 20th century, a second resort, aimed at sporting activities (golf in summer, skiing in winter) was developed in the sector of Crans (Doriot Galofaro 2005). The two resorts developed in parallel in a climate of economic rivalry that lasted almost until the 1980s. Currently, for economic reasons, the two resorts are merged.

The study area covers the territory of 11 municipalities (Figure 1) with various economic profiles: six communes concerned with tourism (Crans-Montana resort), mainly during the winter season; four suburban communes; and a small town (Sierre, 15,800 inhabitants in 2010). 36,500 persons were living in the area in 2010 and the population grew four-fold from 1910 to 2010 with particularly rapid growth between 1960 and 1980. Current usage rates involve about 1,200,000 tourist nights, with two main peaks in February and July-August. Because of its fast growth, Crans-Montana has faced several water shortage events (Reynard 2000a, b) and, because of lack of planning, communes built infrastructures without coordination with neighbouring communes (Clivaz – Reynard 2008). The result is a highly complex network of water infrastructure. Moreover, four municipalities, which historically formed a large commune, were separated in 1905; this increased rivalries between communes and partially explains the lack of planning and coordination (Reynard 2000a,b). Nevertheless, over the last decade, territorial coordination has rapidly improved.

A complex system of water uses

The first part of the research aimed to describe the water use system at the regional scale. We based the analysis on the water use typology elaborated by Reynard et al. (2001) (Table 1). From this first typology, we have focused on the five main uses that derive and/or extract water from the natural system in the study area: drinking water production (use 2, see Table 1), irrigation (3c), water for leisure (in particular irrigation of golf courses and artificial snowmaking) (3e), hydropower generation (4). Water used for industrial activities was not analysed independently because the water used for these activities is in fact drinking water produced by local authorities.

TABLE 1. Water use typology (modified from Reynard et al., 2001). In italics, the water uses present in the Crans-Montana-Sierre area. In the fourth columns we distinguish two categories of users: the producers are the public authorities or private companies that extract water from the hydrosystem and the final consumers are individuals that benefit from the water extraction (e.g. water for drinking is extracted from the natural system by public authorities, and the final consumers are the inhabitants and tourists visiting the region).

N°	Water use categories	Water use subcategories	Types of users
1	Living environment	*Food and reproduction environment for species*	Animal and vegetal species
2	Drinking	*Drinking water consumption*	Public authorities (producers); households, tourists (final consumers)
3	Production	*3a Industries* 3b Cooling of thermal power plants *3c Irrigation* 3d Mineral water production *3e Leisure infrastructures (pools, etc.)*	Private companies Private and semi-public companies Private companies, farmers Private companies Private companies or public authorities
4	Energy production	*Hydropower generation*	Private or semi-public companies
5	Transport of sediments and substances	*5a Transport and absorption of pollutants* *5b Sediment transport*	Public authorities (producers); households, companies (final consumers) –
6	Support for economic and leisure activities	6a Commercial navigation *6b Boating* 6c Gravel extraction 6d Commercial fishing *6e Sport fishing*	Private and public companies Individuals Private and public companies Private companies, fishermen Fishermen
7	Leisure	*7a Landscape* *7b Water sports* 7c Hydrotherapy, Spas	Individuals Private or public companies (producers), individuals (inhabitants and visitors; final consumers)
8	Medical uses	Hydrotherapy	Clinics (producers), individuals (final consumers)
9	Geomorphological changes	*9a Relief changes* *9b Hydrological cycle regulation*	Public authorities (producers), population and companies (final consumers)
10	Strategic reserves	10a Reserves in case of wars *10b Reserves in case of fire*	Public authorities (producers), population (final consumers)

Drinking water production: a complex and fragmented system

In Switzerland, drinking water supply and water sanitation are the responsibility of local authorities (municipalities, called *communes*). The typical management model involves so-called "direct control", that is a system where water supply and sanitation are managed by a specific service (water service) that must be auto-financed (i.e. full cost recovery). In the study area, 11 municipal services are, therefore, responsible for the water supply for the permanent and tourist populations of their own jurisdiction. Because of urban growth (Crans-Montana resort is now an urban area crossing the jurisdictions of six communes), municipal networks are partly interconnected and some infrastructure (e.g. water purification or water sanitation systems, reservoirs) is managed in common by several municipalities (Bréthaut 2012). Nevertheless, interconnection is still incomplete and three independent networks are present (Table 5): one for the tourist resort (6 communes), one around the town of Sierre (4 communes) and one independent (1 commune, St-Léonard). Because of historical common water rights, several communes own sources in the jurisdictions of other communes. Some resources (rivers, some springs) are also a common property of several communes. Finally, the water resource of each commune is very variable (Table 2); some small communes (by population) with large mountain coverage (by space) have very important resources (e.g. Icogne, Mollens), whereas some more urban and populated communes, with quite a small spatial coverage, have much smaller resources (e.g. Randogne, Montana, Cher-

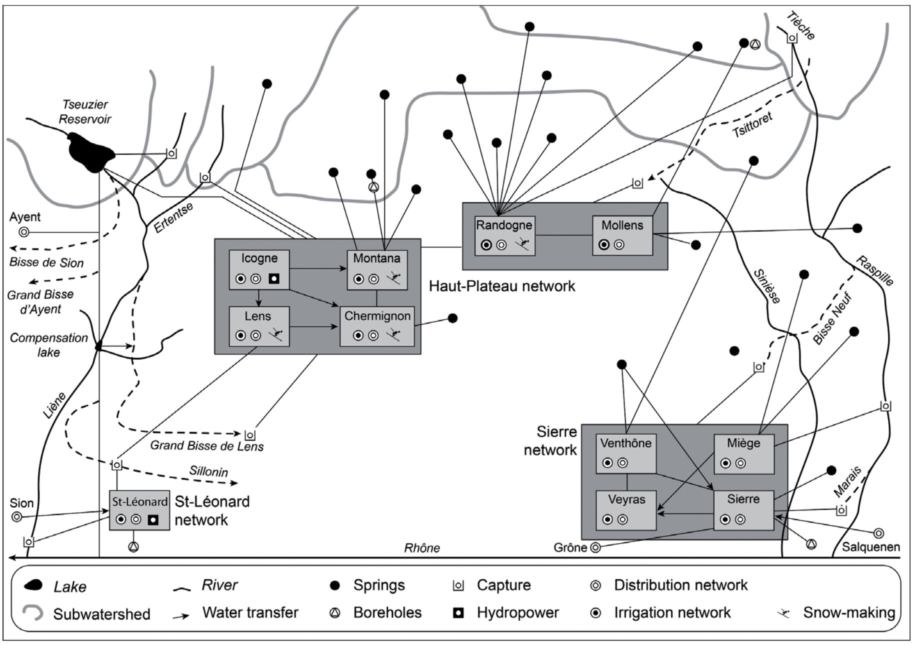

FIGURE 5. The complexity of the water distribution system at the regional scale. Modified from F. Schneider 2012.

mignon, Sierre, Miège, Venthône). One commune has no resource in its own jurisdiction (Veyras) and must buy water from its neighbours. This situation (complexity of infrastructure, variable water rights, variation of resource availability and water needs) creates a very complicated system of water transfers between communes and a real water market at the regional scale (Reynard 2000a and Table 2). Since 1969, the artificial lake of Tseuzier (Figure 8D), that was built initially to store water for hydropower production, is also used to store water for drinking water production, mainly during the winter season (Table 2).

TABLE 2. Origin of drinking water in the 11 municipalities. The major part of the surface water is stored in the Tseuzier lake.

Municipality	Water purchases	Groundwater (springs)	Groundwater (pumping)	Surface water (rivers, lakes)
Icogne		×		×
Lens	×	×		×
Chermignon	×	×		×
Montana	×	×		×
Randogne	×	×		×
Mollens	×	×		×
Miège		×		
Venthône		×		
Veyras	×			
Sierre	×	×	×	
St-Léonard	×		×	

Irrigation: a combination of historical and modern infrastructures

Irrigation is an important water use in the area because of dry climatic conditions (Figure 4). Four kinds of surfaces are irrigated: meadows (Figure 8A), vineyards, golf courses, and gardens and lawns (in the residential zones) (Figure 6). Irrigation of meadows and vineyards is done by using a historical network of channels – called *bisses* –, which have existed since the Middle Ages (e.g. Nahrath et al. 2011). Common-pool institutions – called *consortages* – historically managed the distribution of water and private crops were irrigated individually. Over the last few decades, the commonly managed system has evolved and now the irrigation of meadows and vineyards is a highly complex combination of public and common management, characterized by a lot of informal arrangements (Bréthaut – Nahrath 2011, Nahrath et al. 2011). Water for irrigation is captured from rivers – a practice guaranteed by historical water rights – and transported to the irrigation areas by the *bisses* (Figure 6) and/or underground pipes or galleries (e.g. Mont-Lachaux tunnel, Figure 6). Irrigation of the four golf courses follows the same system. The irrigation in the residential areas is much more complicated. Firstly, the situation varies from one commune to the other. In some communes (e.g. Chermignon), drinking water is used for irrigation, whereas in others (e.g. Montana), networks are separated. In general, quite a lot of so-called drinking water is used for irrigation purposes (see below). Secondly, gardens and lawns in several communes are irrigated with drinking (purified) water. Thirdly, the area is characterized by individual houses (with gardens and lawns) that have important irrigation needs in summer. Finally, because of land-use variations between the different communes, water needs for agriculture are quite different from one municipality to the other (Figure 7).

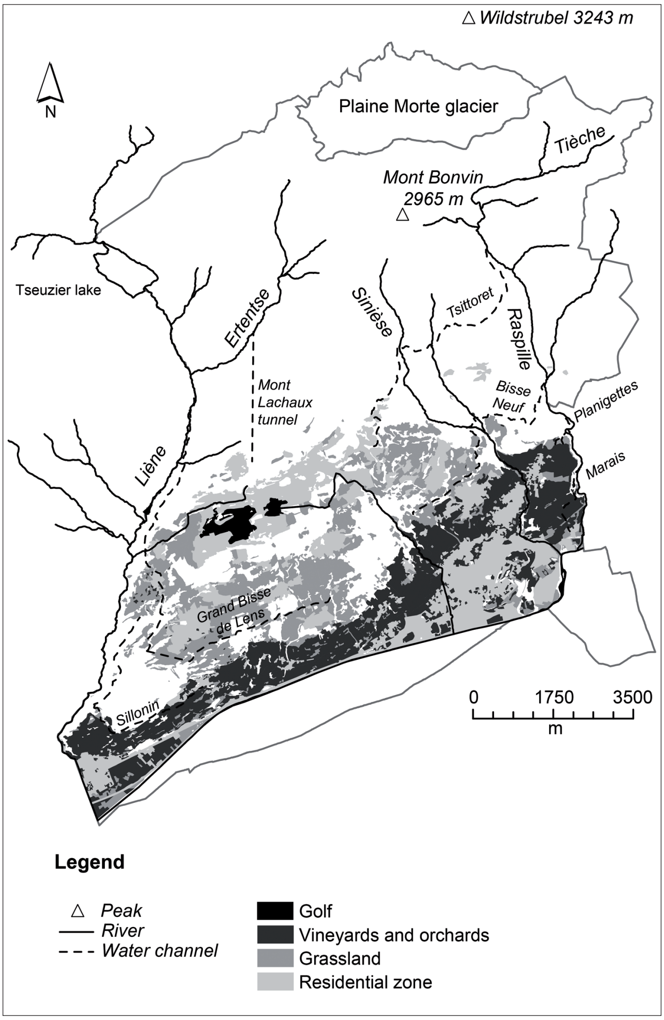

FIGURE 6. Historical water channels and potentially irrigated areas.
Note: not all the grassland and residential areas are irrigated.

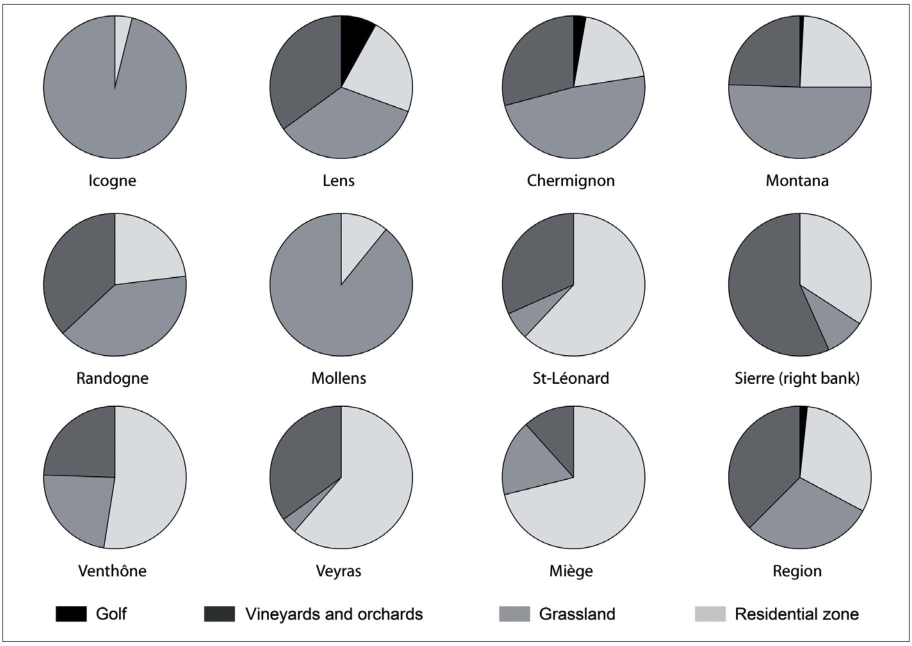

FIGURE 7. Distribution (%) of potential irrigated land in the 11 communes and in the whole area.
Note: data are in percentage and do not take into account the surface differences between the various communes.

Water for tourism: demand variation and specific uses

Tourism is the primary economic sector in the area. With about 40,000 tourist beds, Crans-Montana is one of the largest tourists resorts in Switzerland. Currently, the winter season is dominant, but summer tourism is also well developed and visitors appreciate both hiking and walking activities, and golf. The European Golf Masters, at the beginning of September, is one of the most important golf tournaments in the world. Tourism impacts on water resource management in two ways. Firstly, population fluctuations influence drinking water consumption on two scales: seasonal fluctuations are observed on the seasonal scale (water needs are particularly important during Christmas holidays, in February, and in July and August and, at the other end of the scale, water needs are particularly low in May and November) and, during the high season, peaks of consumption happen at the end of the afternoon when tourists come back to the hotels or apartments from their various activities. It means that the intensity of water consumption is particularly high for a couple of hours. Secondly, tourism has caused the development of specific water uses. The first one – landscape value of water – can be considered as an immaterial use of water. The various lakes present in the tourist resort contribute to the atmosphere of the resort (Clivaz – Reynard 2008) and several walking trails have been developed among the various lakes. Also the *bisses* now have new tourist and cultural functions (Nahrath et al. 2011); they are no longer used only for irrigation but are also used as hiking trails. The other specific uses related to tourism concern infrastructure developed specifically for tourist activities (ice rinks and pools, infrastructures to irrigate the golf courses, and artificial snowmaking infrastructures).

Water used for ice rinks and pools (essentially in hotels) is certainly quite important. Nevertheless, it cannot be studied in detail because this specific water use is integrated in the drinking water systems of the concerned municipalities. Three golf courses (Figure 8B) are present in the resort. The irrigation of the two main courses (the Ballesteros and Nicklaus golf courses) is done with water pumped from an artificial lake (Chermignon lake) created initially for the irrigation of meadows and vineyards, and now used for various uses (irrigation, drinking water production, and artificial snowmaking). Because the irrigation of golf courses can impact on the irrigation of vineyards and meadows, which have priority, the golf courses also have the possibility to pump water from the Tseuzier lake. Finally, water used for artificial snowmaking (Figure 8C) has rapidly increased over the last two decades. Only a part of the ski area is concerned with artificial snowmaking and the water comes from an artificial lake used in summer for irrigation (Chermignon lake) and from the Tseuzier lake. Both sources of water are situated below 1800 m ASL and therefore water must be pumped before use in the ski area. Projects for the extension of the production network are planned.

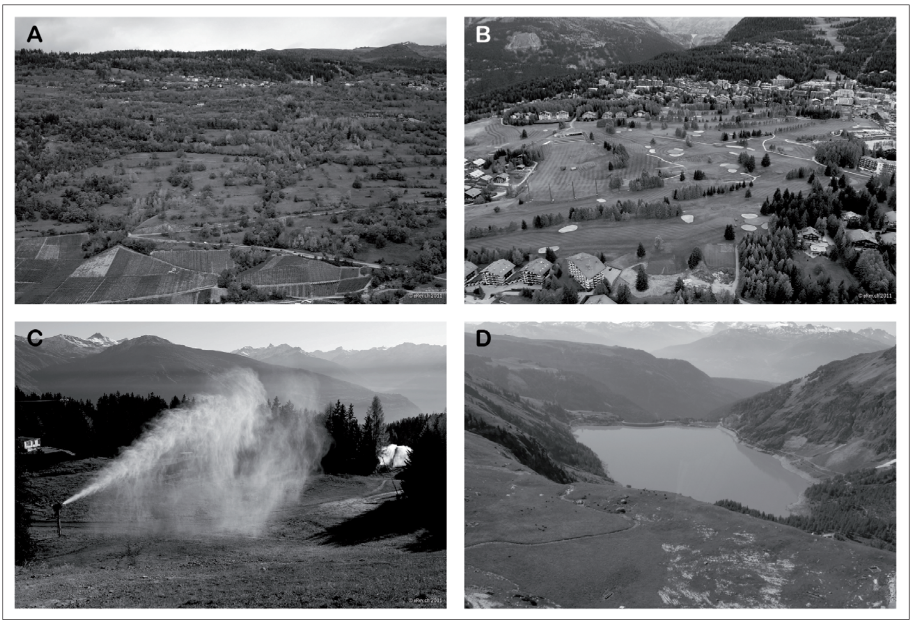

FIGURE 8.
A. Farmland in the area of Chermignon: grassland and vineyards (photo: E. Rey); B. Golf course in Crans (photo: E. Rey); C. Artificial snowmaking (photo: E. Rey); D. Tseuzier artificial lake (photo: E. Reynard).

Hydropower production: the importance of the Tseuzier lake

Hydropower production is the responsibility of a private company that derives water from the Liène River catchment and stores it in the artificial lake of Tseuzier (Figure 8D). The company has a water concession (use right) on surface waters of the Liène River catchment for 80 years, until 2037. The artificial lake was originally built only for hydropower production. Since 1969 (construction of a pipe linking the dam and Crans-Montana), a part of the water stored in the lake has been sold by the hydropower company to some communes (for drinking water, especially in winter), to the golf course company (for irrigation), and to the cableway company (for artificial snowmaking). A large project, which should be realized at the regional scale in the next few years, aims to connect the drinking water network and the hydropower infrastructure in order to better use energy production capacities – due to high topographic gradients – and storage facilities currently available at the regional scale.

Water needs in 2010

The second step of the study was to quantify water used by the various subsystems. We faced two main difficulties. The first one was the lack of data. In fact, some uses are not measured. That is the case with the irrigation of meadows, orchards and vineyards. *Consortages* have water rights (fixed maximum discharge) on rivers during summer but the effective volumes of water that are used are not measured. The use of water flowing in the *bisses* is generally free and no measurement is made. It is, therefore, impossible to quantify water that is effectively used for the irrigation of individual crops. Finally, in the residential areas, there is no possibility of quantifying the part of drinking water used for the irrigation of gardens and lawns. Thus, the quantification of water used for irrigation was done in two ways: hydrological probes were installed on each principal channel and, by using climatic data and agronomic formula, irrigation needs were modelled for each month, by using the MABIA module (Jabloun – Sahli 2012) in WEAP (Water Evaluation And Planning system) model (Raskin et al. 1992). A specific study of water needs in two residential communes, at two different altitudes, was also carried out.

The second problem is related to the heterogeneity of data. Even when data are available (e.g. for drinking water), the quantification at the regional level is difficult. One reason is the lack of long-term measurements (some municipalities have digital data only for the most recent years). Another problem is the variety of time scales; the cableway company has, for example, data only at the season level and has only estimations on the water used at the monthly or daily scales.

Nevertheless, we were able to produce a synthetic view of water used by the various types of users on a monthly scale (Table 3, Figure 9 and 10). We can draw five conclusions:

- Hydropower production derives the largest volumes of water (88.5% of the total uses in 2010);
- The other uses (irrigation, drinking water, artificial snowmaking that totalled 11 million cubic metres in 2010) account for 11.5% of the total uses;
- On the annual scale, drinking water is the largest user (except hydroelectricity), with average needs accounting for 650,000 cubic metres and a total consumption reaching nearly 8 million cubic metres;
- Water needs for drinking water are much more influenced by the use of drinking water for irrigation (in residential areas) than by the variation of population in the tourist high season (winter). In 2010, the average consumption during the winter season (October to March) was 568,000 cubic metres per month, and the summer average consumption (April-September) was 730,000 cubic metres per month. We can therefore consider that in 2010 nearly 1 million cubic metres of distributed drinking water (162,000 cubic metres per month on average during the summer season) was in reality water used for irrigation of lawns and gardens, which represents 1/8 of the annual consumption of so-called drinking water. Moreover, 2010 was a particularly wet year (especially in August), which means that the water needs for irrigation were not very important (Figure 11). In this figure, water needs for irrigation were modelled using the MABIA module in WEAP model for the years 2000-2011. Two groups of years are visible: relatively wet years, with needs reaching 4 to 5 million cubic metres, and dry years, with average needs exceeding 9 million cubic metres. The figure also shows the quantities of water derived by the various *bisses* in 2010 and 2011, as measured by our hydrological probes. It means that during wet years the water derived by the historical channels is sufficient to cover the irrigation needs. 2010 was particularly wet in August; that is the reason why the plant water demand was not so high; it means that a part of the water derived by the historical channels was certainly used to feed wetlands or groundwater storages.
- Water needs for the production of snow and for the irrigation of golf courses are seasonal and not very important at the regional scale. Nevertheless, artificial snow production occurs during the period of low stream and requires, therefore, storing capacities.

TABLE 3. Water uses in the Crans-Montana-Sierre region in 2010. HP = hydropower production. % (1) = Percent of total water uses (without hydropower production). % (2) = Percent of total water uses (with hydropower production).

Month	Hydro-power production	Drinking water	Irrigation	Artificial snow-making	Golf course irrigation	Total without HP	Total with HP
Jan	11,590,400	594,698	0	45,000	0	639,698	12,230,098
Feb	12,636,572	563,532	0	45,000	0	608,532	13,245,104
Mar	3,126,037	576,111	214,192	0	0	790,303	3,916,340
Apr	5,264,112	644,354	359,049	0	4,769	1,008,172	6,272,284
May	18,201,965	640,840	429,819	0	10,403	1,081,062	19,283,027
Jun	0	712,839	263,020	0	17,799	993,658	993,658
Jul	0	937,469	663,870	0	26,523	1,627,862	1,627,862
Aug	1,753,748	767,527	357,029	0	8,909	1,133,465	2,887,213
Sep	5,104,273	676,599	354,191	0	12,159	1,042,949	6,147,222
Oct	8,543,062	582,607	380,292	0	4,221	967,120	9,510,182
Nov	10,128,834	517,419	0	100,000	173	617,592	10,746,426
Dec	9,765,900	574,669	0	100,000	0	674,669	10,440,569
Total	86,114,903	7,788,663	3,021,462	290,000	84,956	11,185,082	97,299,985
Mean		649,055					
% (1)	88.50	8.00	3.11	0.30	0.09	100.00	
% (2)		69.63	27.01	2.59	0.76		

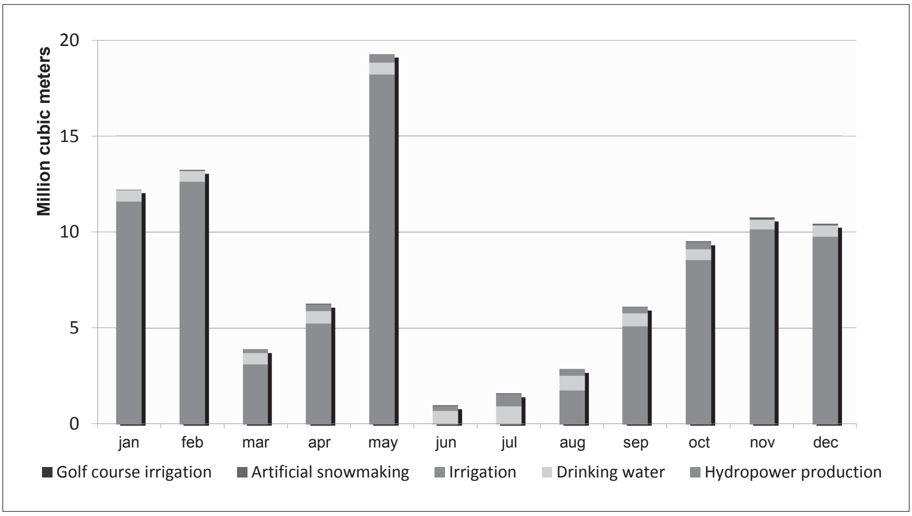

FIGURE 9. Water quantities used in the area of Crans-Montana-Sierre in 2010

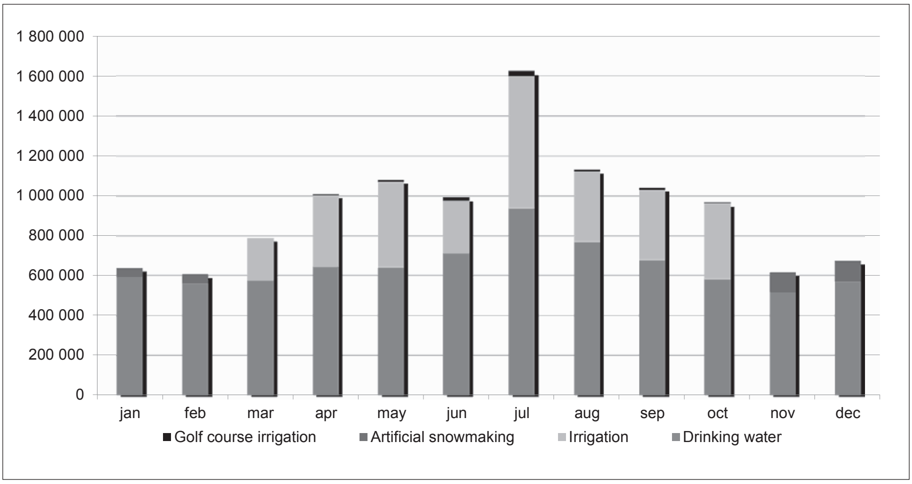

FIGURE 10. Water quantities (without hydropower production) used in the area of Crans-Montana-Sierre in 2010. Values in cubic metres.

Conclusions and perspectives: modelling water uses in 2050

In this paper we have presented the current water use system in the Crans-Montana-Sierre area. We can draw three main conclusions:

- The water use system is very complex. The municipalities are the main actors, responsible for drinking water distribution, but they are not integrated. Three subsystems (Haut-Plateau network, 6 municipalities; Sierre network, 4 municipalities; St-Léonard network, 1 municipality) exist and are not interconnected (Figure 5). They do not correspond to hydrological subdivisions (watersheds), and even within one network there is no correspondence with the hydrological basin limits. In fact, the infrastructure organization is driven by economic factors (e.g. the presence of the Crans-Montana tourist resort) and not by hydrological features, as was already noted by Reynard (2000a, b). Moreover, for historical reasons (in particular, the fact that some individual communes were members of one municipality until 1905), several municipalities own rights to springs on the jurisdiction of another commune. Other usages are much more driven by hydrological factors; this is the case with irrigation and hydropower production. The latter exists only in the Liène River basin, and irrigation derives water from the two main watersheds (Liène and Raspille) to the grassland and crops to irrigate.
- Even if its location is very off-centre, the Tseuzier artificial lake plays a central role in the current water management in the area. In fact, when the reservoir was created in the 1950s, historical water rights of irrigation associations (consortages) were recognized and written into the hydropower concession contract but for

organizational reasons, several water captures of bisses were changed and now the channels are fed directly from the hydropower company pipes. In the 1960s, because of the very fast tourist resort growth and related water shortages, the artificial lake began to be used also for the drinking water supply. Currently, all the six communes of the Haut-Plateau network can be supplied with water stored in the Tseuzier reservoir. During the two last decades, the golf courses and the ski fields also began to be fed from the Tseuzier lake. Currently, a new project aims to derive water from the Raspille watershed and from various sub-watersheds and springs which will then be stored in the Tseuzier lake before being distributed to various users (municipalities, consortages, private companies) and partly turbined in micro power plants. In conclusions, we can now consider that the Tseuzier reservoir is no longer just a hydropower artificial lake, but rather a multifunctional resource for a large part of the region.

- Hydropower production is by far the most important water consumer in the study area, with nearly 90% of the water used derived. Nevertheless, this water is not consumed and is restituted to the water system after usage. It could, therefore, be re-used after usage, with one main problem: the fact that water is restituted in the lower part of the watershed and would have to be pumped in order to be used for other usages. Drinking water distribution is the second water user in the study area. We have observed a larger consumption in summer than in winter, even if the population fluctuations related to tourism (peaks of tourist presence in winter) would suggest that winter demand should be larger than the summer demand. This is related to the very large consumption of so-called drinking water – that is water purified and distributed by the water services –, for irrigating lawns and gardens in the residential zone. We estimate that 1/8 of the drinking water is in reality used for irrigation. The irrigation of grassland, vineyards and orchards is the third water use system in the area in terms of quantities of water derived. Because of lack of data, it has not been possible to quantify the real quantities of water used for irrigation. Measurements carried out in 2010 and 2011 along the historical water channels show that 5 to 6 million cubic metres are derived from the bisses each year. This corresponds more or less to the water needs of crops and meadows – calculated using the MABIA module of WEAP model – in the whole area. During dry years, the water needs are nearly twice as large (Figure 11), a situation that could become more common in the future due to climate change. Water used for tourism infrastructures (golf course irrigation, artificial snowmaking) is much lower than the other uses; they correspond respectively to 0.76% and 2.59% of the total water uses (without hydropower production; see Figure 10) (0.09% and 0.3% of the total uses, including hydropower production; see Figure 9).

The third phase of the project, still underway, aims at comparing the current water use quantities with the water availability (stage 4, Figure 3) and, then, modelling the water needs in 2050 (stage 5, Figure 3), before drawing recommendations for the stakeholders and local authorities. The collected data are introduced into the WEAP (Water Evaluation And Planning system) model (Raskin et al. 1992), in order to estimate the future water demand of the study area. This hydrologic model is distinct from most similar models because of its ability to integrate climatic and socio-economic scenarios. For the elaboration of realistic socio-economic scenarios at the regional scale, we are currently working with a panel of stakeholders representing local authorities, regional administration, associations, and private stakeholders (group RegiEau, Figure 2), which will allow us to establish four different development scenarios.

In order to orient current management and investments, sustainable water management at the local scale needs to take into account both climate change and future socio-economic evolutions to model future water uses. But, realistic modelling needs to know the current structures and mechanisms of management in detail and to collect homogenous quantitative data that will then be used in modelling procedures. The first phase of the MontanAqua research described in this paper shows how water management at the local scale is complex and how data is heterogeneous and difficult to find. It is therefore necessary to develop indicators and systems of data collection and homogenization that could be used for modelling the future uses.

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