CHALLENGES FOR THE PREVISION OF FUTURE WATER DEMANDS. LEARNING FROM TWO CASE STUDIES IN WESTERN SWITZERLAND

Enjeux concernant la prévision des demandes en eau futures. Enseignements de deux études de cas en Suisse occidentale

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ABSTRACT

Water stress and water security depend on hydrological and *anthropogenic factors. Both climate change and socio-economic changes must then be taken into account to fully address future water management at the regional scale. Based on two studies carried out in Western Switzerland, this paper delineates 5 challenges in the prevision of future water demands: (1) scenarios accounting for both hydro-climatic and socio-economic changes should be set up; (2) an appropriate timescale must be defined to establish realistic demographic and socio-economic scenarios for the second part of the 21st century; (3) water users will inevitably adapt to climate change (e.g. development of drip irrigation) and these measures should be taken into account; (4) all water uses should be considered although some are easier to model (e.g. irrigation, drinking water) than others (e.g. immaterial uses such as landscapes, uses based on water quality); (5) a choice must be made among existing indicators, and their related uncertainties, to assess water demands that can be apprehended through measurements (e.g. distribution by water services), modeling (e.g. water needs for different crops under various climate conditions) or the use of proxies (e.g. water used per capita or irrigated hectares). Three main issues emerge for future research: (1) better knowledge of current water demands is required by reconstructing historical trends and developing water use monitoring; (2) modeling of both water quantity and quality is necessary to explore whether water demands can be fully satisfied; (3) water demand scenarios should be co-produced with stakeholders to develop plausible adaptation scenarios.*

KEY WORDS

Water resources, water demands, climate change, anthropogenic changes, Western Switzerland.

RESUME

Enjeux concernant la prévision des demandes en eau futures. Enseignements de deux études de cas en Suisse occidentale.

Le stress et la sécurité hydrique dépendent de facteurs hydrologiques et *anthropiques. Ainsi, autant le changement climatique que les changements socio-économiques doivent être pris en compte afin de prévoir correctement ce que sera la gestion future de l'eau à l'échelle régionale. Sur la base de deux études réalisées en Suisse occidentale, cet article discute de cinq défis qui concernent la prévision des demandes en eau futures : (1) les scénarios futurs devraient tenir compte autant des changements hydro-climatiques que socio-économiques ; (2) la modélisation doit prendre en compte un horizon temporel permettant d'établir des scénarios réalistes concernant l'évolution démographique et socio-économique dans la deuxième partie du 21e siècle ; (3) les usagers de l'eau s'adapteront inévitablement aux changements climatiques (par ex. par le développement de l'irrigation au goutte à goutte) ; ces mesures devraient être prise en compte dans la modélisation ; (4) tous les usages devraient être pris en compte, bien que certains soient plus faciles à modéliser (par ex. irrigation, eau potable) que d'autres (par ex. les usages immatériels, comme l'utilisation paysagère de l'eau ou les usages dépendant de la qualité de l'eau) ; (5) un choix doit être fait entre divers types d'indicateurs, et leur niveau d'incertitude, pour évaluer les demandes en eau, qui peuvent être appréhendées par des mesures (par ex. distribution par les services des eaux), la modélisation (par ex. besoins en eau des cultures sous différentes conditions climatiques) et l'utilisation de proxis (par ex. besoins par habitant, nombre d'hectares irrigués). Trois défis nous attendent pour les recherches futures : (1) établir une meilleure connaissance des demandes en eau actuelles par la reconstructions des évolutions historiques et le développement d'observatoires des usages de l'eau ;*

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(2) modéliser la ressource autant du point de vue quantitatif que qualitatif afin d'explorer la satisfaction globale des demandes en eau ; (3) co-produire des scénarios futurs de demandes en eau avec les usagers afin de développer des scénarios d'adaptation plausibles.

MOTS-CLEFS

Ressources en eau, demandes en eau, changement climatique, changements anthropiques, Suisse occidentale.

1. INTRODUCTION

Since the late 1970s, water issues have become an important topic of the international political agenda due to the coincidence of climatic and anthropogenic changes that enhanced increasing pressures on water resources, both in terms of quantity and quality. In this context, the concepts of water stress, i.e. the capacity of water resources to meet water demands [e.g. Vörösmarty *et al.*, 2000], and water security, i.e. the capacity of a society to mobilize enough water of good quality for all users and also for nature [Bakker, 2012], have become central concepts in hydrological sciences. To be fully addressed, they require the development of innovative modeling tools considering both current and future water resources and demands.

Assessing water stress and water security requires implementing both hydrological *and* anthropogenic factors. Although uncertainties arise during the process and some resources are still difficult to estimate (e.g. groundwater, ice water), the various existing hydrological models have shown to be reliable tools to model current and future water resources availability at the global [e.g. Vörösmarty *et al.*, 2000; Alcamo *et al.*, 2007] and regional scales [e.g. Köplin *et al.*, 2012; Milano *et al.*, 2013]. However, water demands are more difficult to estimate for three main reasons:
(1) Water uses are multiple (*in-situ* uses – navigation – *vs. ex-situ* uses – irrigation; material – water withdrawals – *vs.* immaterial uses – landscape) and they affect either water resources' volumes (e.g. water withdrawals), dynamics (e.g. hydroelectric plants) or quality (e.g. irrigation). Water demands evaluation should consider all these features.
(2) Measuring water demands is a great challenge: statistics are poor and heterogeneous, in particular timescales of data acquisition are irregular and series are generally short rendering difficult reconstruction of past trends [Wada *et al.*, 2011; Grouillet *et al.*, 2015]. Moreover, some uses are difficult to measure (e.g. water use for landscapes) and most assessments rely on proxy data (e.g. per capita values for domestic water demand) or on optimal water needs models (e.g. water demand for irrigation often rely on models computing crops' optimal growth under given climate and soil characteristics).
(3) Uncertainties arise on the terms used to qualify water uses: demands, needs, consumption, withdrawals, derivations are examples of terms often considered as synonyms when they in fact concern only one part of what can be considered the "water use cycle" [Calianno *et al.*, 2014];

This communication addresses some of these challenges by discussing the results of two studies carried out in Western Switzerland from the high alpine mountains to the lowlands of the Rhone valley and Lake Geneva region.

2. CASE STUDIES

The first study focused on nine meso-scale catchments (38–637km^2) of the Vaud catchment, extending from the Jura mountains over the Swiss Plateau to the high alpine mountains (Fig. 1). Climate can be described as continental with mean annual temperatures ranging between 10 and 4°C and mean annual precipitation varying from 865 to 2020mm/year, from low to high altitudes (average over the 1984–2005 period; Milano *et al.*, 2015a). Mountainous catchments thus have nival to nivo-pluvial hydrological regimes whereas over the Swiss Plateau, it is pluvial. Diversified anthropogenic activities also characterize the various catchments. The shores of Lake Geneva and Lake Neuchâtel as well as the Promenthouse catchment are marked by strong urban and peri-urban development. The population tripled in the area since the late 1970s [FOSD-ARE, 2013]. Agricultural activities extend in the plains and piedmont of the Swiss Plateau while dairy cow breeding is favored in mountainous areas, like over the Grande Eau and Sarine catchments.

The second study was carried out in the Crans-Montana-Sierre area (130km^2) located on the northern side of the Rhone River, in the Valais canton (Fig. 1). It is the driest region of Switzerland with mean annual precipitation reaching less than 600mm/year on the valley floor (500m.a.s.l), yet it holds a steep rainfall gradients leading to more than 2 500mm/year at higher altitudes (3 000m.a.s.l), mostly falling as snow during the winter season. The area is also partly covered by a large glacier (Plaine Morte glacier, 7.88km^2 in 2011; Huss *et al.*, 2013) enhancing nival to nivo-glacial hydrological regimes. The economy is mainly driven by tourism and agriculture [Reynard and Bonriposi, 2012; Bonriposi, 2013]. Crans-Montana is one of the largest tourist resorts in Switzerland, with tourist peaks in winter (December-March; ski) and summer (July-September; golf and hiking). Agriculture is dominated by wine-growing below 800m.a.s.l. and cattle breeding that both require important land irrigation during the summer season. Finally, the area was subject to a strong demographic growth all along the 20th century, in particular since the 1970s.

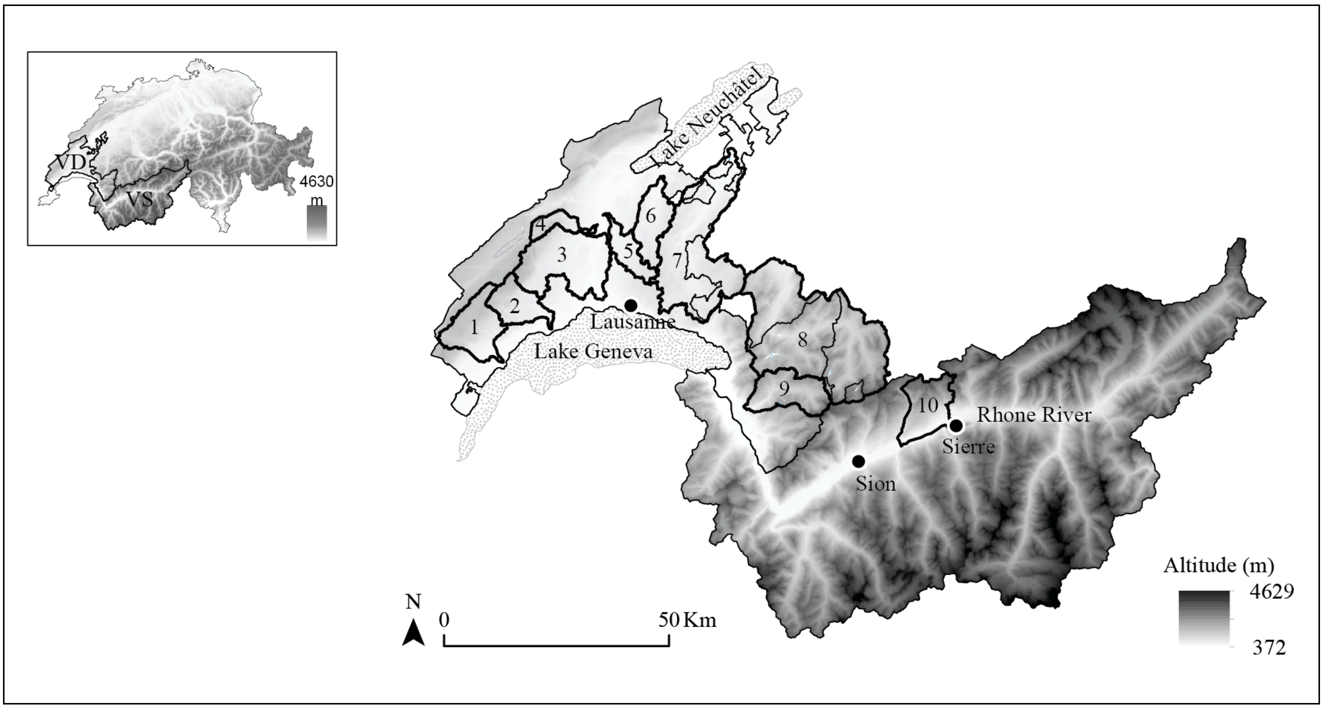

Figure 1: Location of the ten studied areas in Western Switzerland. *VD: Vaud; VS: Valais. Catchments: (1) Promenthouse; (2) Aubonne; (3) Venoge; (4) Nozon; (5) Talent; (6) Mentue; (7) Broye; (8) Grande Eau; (9) Sarine.*

3. METHODS

3.1 Addressing water stress in Western Switzerland

Two methods were developed in order to address water stress and its potential evolution in Western Switzerland. The first approach was carried at a cantonal scale with the aim of suggesting a homogeneous and common method for all catchments to evaluate pressures applied on water resources. Applied over each catchment, it describes the current state, enables comparison and highlights areas where tensions are most likely to occur by the 2060 horizon [Milano *et al.*, 2015c]. For synthesis purposes, only the results for the Promenthouse and Venoge catchments are presented in this paper. They are respectively representative of cantonal catchments where urban and agricultural pressures applied on water resources are highest. The second approach was carried at a more local scale with the aim of describing the current water system, including water resources, demands and management structures, and defining how the system could evolve around 2040-2050, in collaboration with stakeholders [Reynard *et al.*, 2014a,b]. The aim was to define various scenarios of territorial evolution and to estimate what could be their impacts on water demands and water stress.

3.2 An integrated modeling approach to assess water stress in the Vaud canton

An integrated modeling approach was set up to assess water stress under climatic and/or anthropogenic changes in the Vaud canton [Milano *et al.* 2015a,b,c]. It is based on a water stress index, i.e. a ratio of monthly water needs to monthly available river freshwater resources [Shiklomanov, 1991], which was computed over a past reference period (1984–2005) and by the 2060 horizon (2050–2071). Available freshwater resources were considered as the daily contribution of rapid, delayed and slow runoffs modeled by the semi-distributed and process-oriented PREVAH model [Viviroli *et al.*, 2009]. For the reference period, daily meteorological data were collected from the automatic meteorological network of Switzerland [MeteoSwiss, 2008] and interpolated according to the detrended inverse distance weighting method. For prospective modeling, delta change signals extracted from ten regional climate models forced with the IPCC A1B greenhouse gas emission scenario [Bosshard *et al.*, 2011; CH2011, 2011] were applied on daily temperature and precipitation series.

Water needs were considered as the daily volume required for crops' optimal growth, animals drinking purposes and any facilities connected to the communal network. For each commune of each catchment, crop, livestock and urban specific water needs were computed and multiplied to the commune's irrigated area, herd-heads and population, respectively [Milano *et al.*, 2015c]. Future water needs were estimated based on a business-as-usual scenario. Impacts of climate change on current irrigated crops and surface areas were explored. Livestock past evolution trends were carried on and a demographic growth scenario provided by the cantonal statistic office [Statistique Vaud, 2011] was used.

3.3 Anticipating water stress in the Crans-Montana-Sierre region

Water stress was addressed in the Crans-Montana-Sierre region by describing the three main features of the water system, i.e. water resources, demands and management structure. Water resources assessment combined climatological and hydrological measurements in the field, geophysical surveys to estimate the ice volume of the Plaine Morte glacier [Huss *et al.*, 2013], hydrogeological and isotope/geochemical analyses to assess the contribution of snow- and ice-melt to river runoff [Finger *et al.*, 2013], and glaciological and hydrological modeling to assess the total available water volumes [Reynard *et al.*, 2014a]. The water use system was assessed through an intense documentary survey in the 11 communes of the study area [Bonriposi, 2013]. Five main water use subsystems were taken into account: urban water, irrigation, artificial snowmaking, golfcourse irrigation, and hydropower production. The latter was assessed independently based on the fact that it is rather a derivation of water than a real water use. Water demands were computed for each commune at the monthly timescale. Changes in the future (2040 horizon) were divided into two groups: climate– and society– driven changes. Glaciological and hydrological changes were forced with the same regional climatic models and greenhouse gas emission scenario as in the Vaud study [Bosshard *et al.*, 2011; CH2011, 2011] and modeled by the Glacier Evolution Runoff Model (GERM) [Huss *et al.*, 2008] and the hydrological model PIHM [Kumar, 2009], respectively [see Reynard *et al.*, 2014a for details].

Future water demands were computed based on four different regional development scenarios [Schneider and Rist, 2013; Schneider *et al.*, 2014]. The first three (growth strategy, stabilization strategy, moderation strategy) were elaborated by the researchers involved in the project. For each vision a set of indicators concerning demographic trends, water consumption saving techniques, spatial planning, tourism, agriculture, viticulture, hydropower production, development of infrastructures (pipelines, storage), institutional reforms (regional collaboration), and water rights allocation (residual flows for ecological purposes) were elaborated. The first vision is close to a business-as-usual scenario with regional development supported by economic growth, based on mass tourism and expansion of built areas. In this scenario, population rapidly increases in the next decades and agriculture continues to lose importance. In the second vision, water management aims at optimizing water consumption (water demand management, irrigation techniques improvement). The third strategy focuses on improving the quality of life of residents and visitors, and individual measures for water management are promoted. These three scenarios were discussed with a group of local stakeholders representing various interests (public administrations, politicians, associations, private companies, etc.). They suggested a fourth vision, considered as a shared vision of future development, in which economic growth is balanced by social needs (equity between citizens) and ecological considerations. All four visions were then translated into changes in land-use and water demands, and compared to current demands.

4. RESULTS AND DISCUSSION

4.1 Impacts of climatic and anthropogenic changes on the water system

Currently, eastern catchments of the Vaud canton (Grande Eau, Sarine, Broye, Mentue) undergo no stress and it should remain likewise by the 2060 horizon (not shown). In opposition, western catchments undergo moderate water stress from June to August, i.e. water needs amount to 30–40% of the available freshwater. This can mainly be attributed to high urban water needs (Fig. 2a). In highly irrigated catchments, water needs can amount to more than 80% of the available resources during the same period (Fig. 2b). By the 2060 horizon, anthropogenic changes could lead to high to severe water stress in highly urbanized catchments (Fig. 2a) and highly irrigated catchments should remain under severe water stress (Fig. 2b). These states should be exacerbated under climate change, as low flows should be longer and more intense. Under both climatic and anthropogenic changes, catchments could experience moderate water stress starting in May and water needs should exceed more than 80% of the available freshwater resources from June to August (Fig. 2a & 2b). In the Valais canton, the area of Crans-Montana-Sierre currently experiences seasonal water stress during the winter months (especially February and March) due to low flows and high water demands related to tourism (seasonal population, artificial snowmaking; Fig. 2c). A second period under water stress can also be identified during the last summer months (August and September) due to low flows and high irrigation water demands (Fig. 2c). By the mid-21st century, water stress during late summer is projected to get worse due to increasing urban and irrigation water demands according to scenario 1 and 2, respectively (Table 1). According to scenario 3 and 4, changes in water stress should remain low thanks to the support of low flows by higher spring snow- and ice- melt, due to climate change, and improvements in water management (not shown).

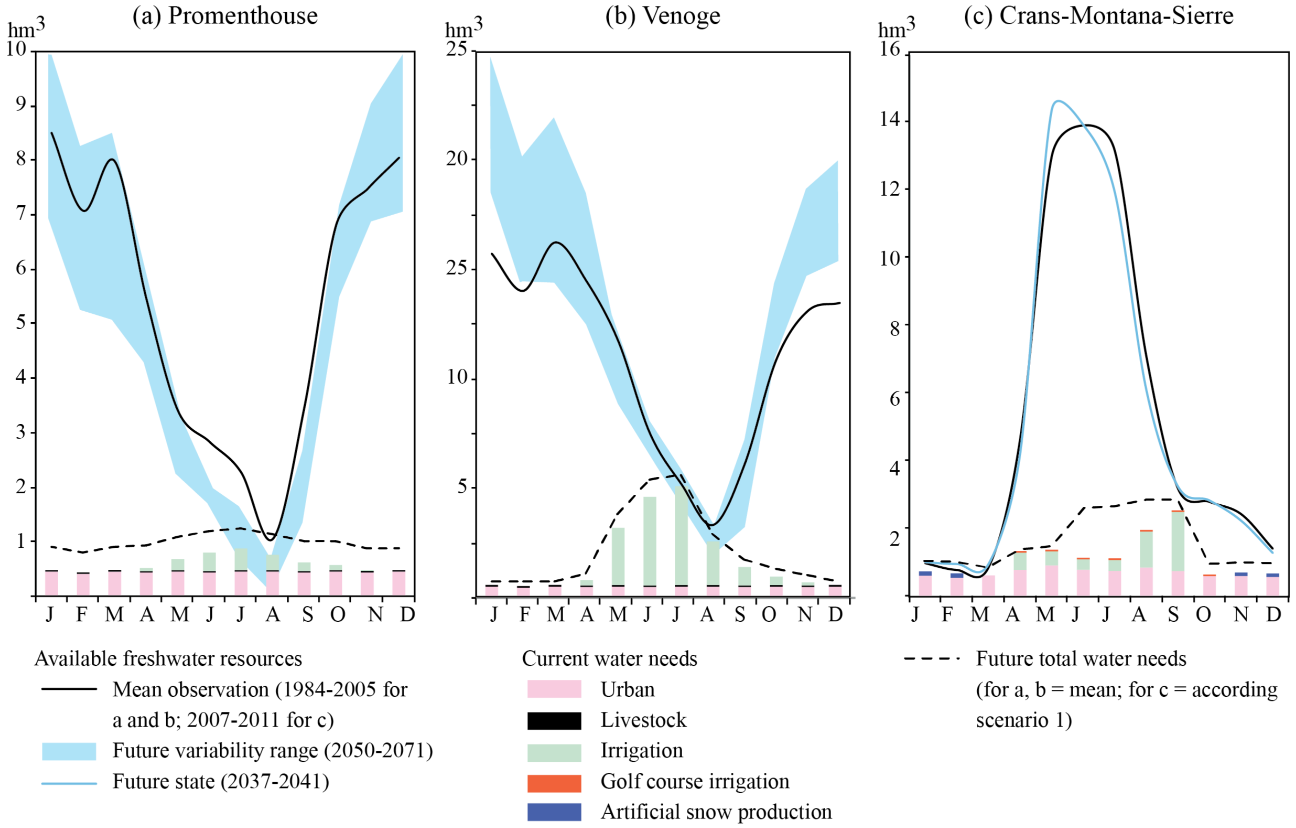

Figure 2: Current water resources and demands, and their potential evolution by the mid-century for the (a) Promenthouse catchment, (b) Venoge catchment, and (c) Crans-Montana-Sierre area. For the Crans-Montana-Sierre area, current and future water needs are shown for the dry year 2011 and scenario 1, respectively.

4.2 Combining climate and anthropic factors

Out of these two regional studies, the first main challenge that arises is the need to explore the water system evolution considering both hydro-climatic and anthropic factors. In the Vaud canton, water stress was first addressed under anthropogenic changes, then under climatic changes and finally under both changes. It highlighted the influence of each factor on water stress occurrence: anthropogenic changes should induce higher water needs, increasing pressures applied on water resources, while climate change should enhance longer and more intense low flows, decreasing water resources availability. Water stress could then occur on a longer period and water needs exceed 80% of the available river resources during the summer season in the 2060 horizon. Changes thus have cumulative effects that must be put forward to explore possible water management plans. In the Crans-Montana-Sierre area, impacts of climate and anthropogenic factors were not assessed separately. However, it was demonstrated that in the 2040 horizon, anthropogenic changes could have a stronger influence on water stress than hydro-climatic changes. Indeed, by the 2040 horizon, total water resources availability should not change mainly because of the high contribution of glacier melting to summer runoff (Fig. 2c). According to the considered regional development scenarios, different sectors could apply higher pressures on water resources in the 2040 horizon (Table 1) and enhance water stress during the second half of the summer. In the Crans-Montana-Sierre region, occurrence of water stress in the 2040 horizon should then be caused by changes in water demands and its degree of severity depend on water management options. The situation could nonetheless quickly change after 2060 as a strong decrease in runoff is projected during the second half of the summer due to the glacier extinction (not shown).

	Drinking water	Irrigation	Golf course irrigation	Artificial snowmaking	Total (through brackets maximum needs)	Hydropower production
Current water needs (million m^3)						
2010 – normal year	7.7	2.4	0.08	0.3	10.5	67.5
2011 – dry year	8.2	4.8	0.09	0.45	13.6	61.2
Future water needs						
Scenario 1	+33.5%	–18.7%	+7.8%	+77%	+24% (+59%)	?
Scenario 2	+7.6%	+32.6%	+14.5%	–19%	+19% (+60%)	?
Scenario 3	–9.6/–16.8%	–34%	+6.8%	–100%	–13% (+18%)	?
Scenario 4 (Stakeholders)	+7.6%	–0.2%	+5.8%	–19%	–3% (+49%)	?

Table 1: Current water needs in the Crans-Montana-Sierre area and possible changes by the 2040 horizon according to four regional development scenarios [after Reynard *et al.*, 2014a,b, modified].

4.3 The timescale issue

A second issue is the need to define an appropriate timescale to establish realistic demographic and socio-economic scenarios for the second part of the 21st century. In the Vaud canton study, it was decided to estimate water needs based on the future climate period 2050–2071 according to a business-as-usual scenario. Such approach enables highlighting a relative change in water stress compared to the current state and defining the most vulnerable regions to water stress. Nonetheless, unlike other regional studies that explored water stress on an annual basis [e.g. Menzel & Matovell, 2009; Milano et al., 2013], water stress was here explored at a monthly time-step, which enable highlighting the extent of water stress episodes and the most-at-risk seasons. The study carried out in the Crans-Montana-Sierre region brought the timescale issue a step further. On one hand, a decrease in total water availability is projected to occur after 2060 due to significant changes in glacial extent. Water shortages are then most likely to happen after 2060. On the other hand, in agreement with stakeholders, it is assumed impossible to delineate socio-economic changes at the scale of a group of communes due to rapid economic and territorial changes. It was then decided to focus on the period 2037–2040 to develop *realistic* regional development scenarios with the local stakeholders and to estimate future water needs.

4.4 Taking into account adaptation measures

Water users will inevitably adapt to climate change (e.g. development of drip irrigation) and these measures should be taken into account in future demand modeling. Before taking adaptation measures into account, the water system must be fully known and correctly represented. It is only once the water system is correctly represented in its present form that hypotheses on future development and adaptation measures can be considered (e.g. water derivation, development of drip irrigation, etc.). These limits call for further studies in the Vaud canton. Water needs were only explored according to a business-as-usual scenario. Irrigated crops and surface areas were assumed to remain as are although they are mostly likely to evolve according to food needs and policies. Building alternative water use scenarios in collaboration with stakeholders like in the Crans-Montana-Sierre region could improve knowledge on the capacity of water management options to reduce water tensions. Moreover, water needs were assumed to be solely supplied by rivers although 22% and 13% comes from groundwater and lake pumping, respectively [SGWA, 2004]. Changes in pressures applied on river water resources was then explored and the most vulnerable rivers were identified. In the Crans-Montana-Sierre area, this issue was partly solved since several regional development scenarios were set up, including adaptation measures (e.g. individual measures for saving rainwater in scenario 3, storage facilities development in scenario 2).

4.5 Taking into account all uses

All water uses should be considered although some are easier to model (e.g. irrigation, drinking water) than others (e.g. immaterial uses such as landscapes, uses based on water quality). This issue was only partly addressed in the two studies. In the Vaud canton, as the objective was to distinguish the regions most prone to water stress, only urban water supply, irrigation and water for livestock were considered. In Crans-Montana-Sierre, the use of water for tourism (golf course irrigation, artificial snowmaking) was also taken into account. Hydropower production, which is a sector that derivates large amounts of water, was only partly integrated in the analysis as in the future it was supposed not to evolve. Ecological needs, immaterial uses (landscape) and water quality issues were not addressed, which is a limit to both studies.

4.6 The data issue

Finally, the method used to estimate water demands affects the water stress state. The latter will be chosen according to the knowledge of the study area and the available datasets, for which related uncertainties must be known and mentioned. Different measures were here applied to estimate water needs. Regarding irrigation, the crop coefficient approach was applied [Allen *et al.*, 1998]. It aims at modeling the volume of freshwater required, in addition to rainfall, to meet crops' maximum evapotranspiration according to climatic, crop pattern and soil characteristics [Bonriposi, 2013; Milano *et al.*, 2015b]. The obtained values might be overestimated compared to the actual water demand expressed by farmers. For urban water needs, two different methods were explored. In the Vaud canton, annual national proxis (water used per capita) were used due to a lack of more detailed data. The latter presents two downsides: (i) monthly variations related to seasonal changes and touristic activities are hidden, and (ii) local discrepancies cannot be underlined. The same issue appears for livestock water needs, which depend on the animals' growth stage and food consumption. Such approach are often used at global and regional scales and are judged robust enough to provide a first overview of where water tensions are most likely to occur. In Crans-Montana-Sierre, data provided by the municipalities (water distribution statistics) were combined with proxies (water volumes per capita combined with proxy data concerning tourist population). Although the use of proxies gives a rough estimation of actual water uses, daily and monthly values provide an accurate picture of how water demands evolve throughout the year. It also showed in the Crans-Montana-Sierre region that 1/8 of the current distributed urban water is used for irrigation of gardens and lawns (Reynard and Bonriposi, 2012).

5. CONCLUSION AND PROSPECT

Out of these two studies, three main challenges emerge for future research: (1) better knowledge of current water demands and developing water use monitoring is required to understand how water demands evolved through time and thus to build appropriate future water use scenarios; (2) modeling both water quantity and quality is necessary to explore whether water demands could be fully satisfied in the near future; (3) water demand scenarios should be co-produced with stakeholders to develop plausible adaptation scenarios. This last perspective faces several challenges notably in the communication between researchers and stakeholders. Despite acquiring a common language, defining an accurate period of time for future studies is a major stake. Hydro-climatic scenarios in the short-term (upcoming years) is still an uneasy task for scientists while for decision makers timescales of several decades are not common and difficult to address as they have to report tangible and easy-to-assess results to local population.

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