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Electronic version

URL: <https://journals.openedition.org/rga/6717>

DOI: 10.4000/rga.6717

ISSN: 1760-7426

This article is a translation of:

La méthode des analogues : reproduire le caractère saisonnier de la distribution d'eau potable dans les stations touristiques de montagne - URL : <https://journals.openedition.org/rga/6704> [fr]

Publisher:

Association pour la diffusion de la recherche alpine, UGA Éditions/Université Grenoble Alpes

Electronic reference

Martin Calianno, "The Analogues Method: Reproducing the Seasonality of Drinking Water Distribution in Mountain Tourist Resorts", *Journal of Alpine Research | Revue de géographie alpine* [Online], 108-1 | 2020, Online since 03 April 2020, connection on 08 December 2022. URL: <http://journals.openedition.org/rga/6717> ; DOI: <https://doi.org/10.4000/rga.6717>

This text was automatically generated on 8 December 2022.

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Martin Calianno

Acknowledgments

I would like to thank Emmanuel Reynard for his comments and recommendations. Also, my regards go to Megève's water services team (Emmanuel Gannaz, Sylvie De- biève, Carole Talotti, Julien Branchereau and Julien Beline) for their invaluable collaboration and enthusiasm during the field visits. Finally, I thank Marianne Milano, Georges-Marie Saulnier, André Musy and Aude Soureillat for their input on this research.

Introduction

- 1 Water management is a crucial issue for tourist resorts in order to ensure their attractiveness as a tourist resource, for hydrotherapy, landscape, nautical sports and snow offers (Reynard, 2001), as well as for the supply of drinking water to temporary and residential populations (Gössling, 2002).
- 2 The pressures on water resources in tourist areas are generally concentrated during periods of low flow, namely winter in the Alps (Marnezy, 2008). The time lag between water supply and demand in tourist resorts can cause water shortages, which could be more frequent with the expected levels of urban and demographic growth (Buytaert and de Bièvre, 2012) and with the impact of climate change on the availability of water resources (Milano *et al.*, 2013) and on hydrological regimes (Saulnier *et al.*, 2011; Beniston and Stoffel, 2013).
- 3 To assess the effects of anthropogenic and climatic changes on the water balance, models combining the estimation of water resources and demands help to identify the

conditions leading to water scarcity in regions such as the Alps (Vanham *et al.*, 2009; Reynard *et al.*, 2014; Milano *et al.*, 2015). The first problem encountered by these approaches is the low availability of water use data on a local scale and with sufficient temporal resolution. The interannual seasonality of uses is rarely known, which calls for the development of demand-driven approaches (Grouillet *et al.*, 2015), capable of feeding these models with realistic water use behaviors. The need for data to assess the variability of the demand for drinking water is even greater in tourist resorts, to help managers guarantee water distribution during tourist peak seasons (Leroy, 2015).

- 4 In this work, the mountain tourist resort is chosen as a case study for its particular seasonality in the distribution of drinking water. These stations have a high proportion of secondary accommodation and tourist accommodation, which leads to strong seasonal variations: demand can double in a few weeks, even days, (Nahrath and Bréthaut, 2016). In addition, demand depends on the types of users and their practices, which must be identified for specific territories (Calianno *et al.*, 2018).
- 5 Previous works have developed methods to overcome this lack of water usage data. Marnezy (2008) conceptually described the seasonality of demand for mountain resorts. This seasonality can be assessed via indirect data (proxy) such as the tonnage of municipal waste, allowing the tourist population to be estimated (Reynard, 2001). Charnay (2010) collected monthly municipal data to produce an annual report on water withdrawals in the Giffre watershed (Haute-Savoie). Other studies have simulated the water demand in mountain resorts by combining hydrological and climatic data with demographic and economic data (Soboll and Schmude, 2011; Leroy, 2015). Klug *et al.* (2012) have differentiated the annual water demand rates of residents and tourists for the Alpine region. In most research, the unit demand (in liters/day/person) does not vary over time; the variability of demand is only governed by the evolution of the population (Viviroli *et al.*, 2007; Buytaert and de Bièvre, 2012). Vanham *et al.* (2011) distinguish unit requests according to use (domestic, municipal, industrial and agricultural) but also fixed throughout the year. These examples illustrate a second problem: the lack of direct measures of water use and the widespread use of the proxy. It is common for small mountain municipalities to lack the technical means to collect data on the distribution of drinking water. In Switzerland, some do not have a water meter and apply a flat rate (Reynard, 2001). On the scale of the municipal distribution, data exist and are generally of sufficient time resolution (daily, hourly). However, the spatial scale concerned is rough because it encompasses the entire municipality. User-level data (water meter) is available via billing, but is mostly only collected annually (Bonriposi, 2013).
- 6 The main objective of this work is to make up for these lack of usage data by providing a detailed assessment of the seasonality of drinking water uses in a case of mountain tourist territory (the Megève resort), at the scale of users and with satisfactory temporal resolution. The problem of the lack of direct measurements is solved by monitoring water meters (drinking water supplies) on a sample of buildings and monitored daily. The problem of data availability is addressed by proposing the analogues method, a strategy which estimates the distribution of municipal drinking water based on the data from the monitoring and using the concept of delivery regimes to highlight the water use seasonality (Calianno *et al.*, 2018). The particularity of this method is that it distinguishes the building parameters that can influence the use of water: allocation (e.g. housing, shop, office, hotel), housing (house, apartments) and

residence regime (permanent, temporary). To promote reproducibility, the reasoning is based on water delivery values per territorial unit (per accommodation unit, bed, workplace) and not per person. The analogues method is intended for decision-makers and urban planners, as it makes it possible to predict the seasonality of water distribution in territories where little data is available.

- 7 The first part of this article presents the case study (Megève). The second describes the methodology developed (monitoring, typology of delivery regimes and analogues method). The third part presents the results and the last part combines the discussion and the conclusion.

Study Area: the Alpine Tourist Resort of Megève

Geographic Context

- 8 The commune of Megève is located in south-west France, between the Aravis and the Beaufortain, at an altitude ranging from 1,027 to 2,485 m (Fig. 1). The tourist resort is active in winter (445 km of ski slopes) and in summer (hiking, sporting and cultural events). Given the proximity of the Geneva conurbation, the station also welcomes a large proportion of temporary residents for weekend stays.

Figure 1. Location of Megève resort

- 9 Megève includes a high proportion of secondary housing. Temporary residents usually come in summer and during Christmas and New Years, as well as for skiing in winter. Megève is internationally recognized as a luxury resort, with many high-end hotels and a large urban spread of chalets for second homes. In 2014, the permanent population was 3,292 residents. In the same year, the accommodation capacity (secondary

residents and tourist beds) was estimated at 48,000 (Branchereau, 2015). Out of a total of 9,372 dwellings, only 21.6% were primary residences, 76.6% were secondary residences and 1.8% were vacant dwellings (Insee, 2016). There are 18% of houses for 82% of apartments.

Water Uses

- 10 The Megève drinking water distribution network is managed by the municipality. Its operation is described in detail by Leroy (2015). Most of uses are linked to drinking water, used for domestic, leisure (sports and swimming pools, etc.), livestock and municipal purposes. The main water resources are withdrawn within the municipality (Fig. 1c).
- 11 The distribution and height of water in the reservoirs are monitored in real time. Each building connected to the network has its own meter, which is read once a year for volumetric billing (Branchereau, 2015). Uses outside the drinking water network include water for cattle in mountain pastures (taken from torrents) and the production of artificial snow (via hillside reservoirs).

Methodology

- 12 This section presents the method used for the analysis of distribution data, the monitoring of water meters and the analogues method (Fig. 2).
- 13 The data are analyzed according to the concept of water use cycle (Calianno *et al.*, 2017), which distinguishes the different stages of water flow in a water use system. The analysis is carried out at the delivery stage (at the water meter: one meter per building) and at the distribution stage (total quantity flowing into the network).

Figure 2. Schematic synthesis of the methodology used

Collection of Municipal Drinking Water Distribution Data

- 14 The daily drinking water distribution series were collected from the municipality, from February 2015 to June 2017 (Figure 2a).

Monitoring of Drinking Water at the Delivery Scale

- 15 Hourly time series of drinking water supply were collected on a sample of 10 water meters using dataloggers, from 2015 to 2016 (Fig. 2b). The choice of users for the sample was made in collaboration with municipal technicians to guarantee a variety of user profiles (Table 1). We recommend equipping at least 2 meters for each category of buildings with supposedly different usage dynamics, depending on the use (offices, housing, farms, shops and hotels), habitat (house, apartment) and the regime of residence (permanent, temporary).

Table 1. Sample of buildings chosen for the monitoring

Sample	Residency	Characteristics
Offices	Permanent	33 work places
House 1 (chalet)	Permanent	garden, outdoor pool
House 2	Permanent	garden
House 3 (chalet)	Temporary	garden, indoor pool
House 4 (chalet)	Temporary	garden
Hotel 1	Temporary	4 stars, 280 beds, spa, 2 pools, restaurant
Hotel 2	Temporary	5 stars, 48 beds, spa, indoor pool, restaurant
Apartment block	Permanent	5 housings
Apartment block & shops	Temporary + permanent	39 housings (shops included)
Farm (housing)	Temporary	garden
Farm (barn)	Temporary	31 milk cows, milk room

- 16 The farm was controlled manually every month for a year (2015). The hourly input series have been aggregated in daily time steps in order to obtain a readable signal over the entire year. To generalize this data, the gross contribution values (l / day) have been transformed into unit distribution values (UD) by dividing the gross values by the number of units for each assignment: l / day / dwelling (building) , l / day / bed (hotel), l / day / workplace (offices) and l / day / cow (stable). If no unit is present, the input is assumed to be zero.

Water Delivery Regimes and Typology

- 17 The drinking water supply time series have been normalized (Fig. 2c) to produce regimes that focus on the dynamics of use (Calianno *et al.*, 2018). For daily series, the regime coefficient (RC_i) is the normalized value obtained by dividing the daily average of the intakes by the interannual average (Eq. 1).

Equation 1 :

$$RC_i = \frac{DELIVERY_i}{DELIVERY(interannual)}$$

- 18 With:

- $DELIVERY_i$ = value of the delivery on the considered day averaged over several years,
- $DELIVERY(inter-annual)$ = mean delivery over the considered period,

- i = the considered day.

19 Full annual data were available for 2015 and 2016. Therefore, daily values were averaged over these two years. A RCi value of zero indicates that there is no water input; while a value of 1 means that the intake is equal to the inter-annual average. The regimes were selected and classified manually to obtain a typology whose seasonality is characteristic of the type of habitat, the use of water and the regime of residence (temporary or permanent).

Analogues Method

20 To reconstruct the dynamics of municipal distribution when data on water uses are not available for a territory or for urban planning, we propose the analogues method (Fig. 2d). This method is based on the typology of delivery regimes to recreate the municipal distribution signal, according to the following steps:

1. Clean the time series of the typology of deliveries (abnormal peaks, outliers) and average the regimes of similar dynamics.
2. Extract from this typology the regimes that best represent the diversity of the dynamics of water use in the chosen territory.
3. Multiply each regime by its interannual average unit value to transform dimensionless delivery regimes into volumetric values (in l / day per accommodation, bed, workplace, cow, etc.).
4. Multiply each pattern thus created by the number of units present in the territory: number of dwellings (temporary or permanent), beds, workplaces or cows (see table 2 for Megève).
5. Add the volumetric regimes obtained (in l / day) to recreate a synthetic signal for the distribution of drinking water. An estimated proportion of network losses is added. The analogues method is formalized in the following equation (equation 2).

Equation 2

$$[1 + l/100] \times \sum_{pattern=1}^n [RC \times UM(interannual) \times u]$$

21 With:

- RC = normalised delivery regime coefficient,
- UM (interannual) (l/day/unit) = unitary mean delivery over the sampled period (e.g.: dwelling, work place, bed, cow),
- = number of units present throughout the territory,
- (%) = percentage of water loss in the municipal network (0 to 100%).

Table 2. Total water use units in Megève

Type	Unit	Amount
Houses - permanent residents	Dwellings	305
Houses (chalets) - temporary residents	Dwellings	1388
Hotels	Beds	11036
Apartment blocks - permanent residents	Dwellings	1367
Apartment blocks - temporary residents	Dwellings	6226
Offices	Work places	150
Barns	Cows	870

- 22 In Megève, the proportion of permanent and temporary residences is not known for each type of building (house, apartments). The municipal proportion is therefore applied by default for all dwellings (22% are permanent, 78% are temporary; Insee (2016)). The number of workplaces in the municipality is estimated at 150. The loss rate from the distribution network is set at 20% (Branchereau, 2015).

Results

Dynamics of Distribution

- 23 The municipal drinking water distribution time series from February 2015 to June 2017 (Figure 3) shows marked variability with values ranging from 1,500 m³ / d in May 2015 to more than 6,000 m³ / d in January 2017.

Figure 3. Municipal drinking water distribution in Megève.

The blank parts in drinking water distribution time series indicate periods without data.

Data source: Megève Municipal Water Services.

- 24 Two types of distribution dynamics are observed and are closely linked to the variation in the temporary population (tourists and temporary residents), present at low frequency (on a monthly scale) and at high frequency (on a weekly scale). Such a regime with two levels of variability is shown diagrammatically in Figure 4.

Figure 4. Schematic representation of Megève municipal drinking water distribution dynamics

- 25 The years analyzed (2015, 2016 and the first half of 2017) present three waves of low frequency with high distribution values, corresponding to the high tourist seasons:
- late December to early January: Christmas and New Year (ski season),
 - February: winter school holidays (ski season),
 - July-August: school holidays (summer season).
- 26 The two peaks of the ski season presents the highest distribution values ($> 5,000 \text{ m}^3 / \text{d}$), while the summer peaks are lower ($3,000 - 4,000 \text{ m}^3 / \text{d}$). The lowest distribution values goes from April to June and from September to early December, corresponding to the low seasons of spring and fall. At the same time, peaks high frequency peaks show increased distribution on weekends, mainly in high season (winter, summer) and mid season (January, March, December). These high frequency peaks, indicating “weekend” visitors, are stronger during the high winter season than during the high summer season.

Typology of Delivery Regimes

- 27 The series measured on the sample of water meters were normalized and a typology of delivery regimes was selected according to the method described in point 3.3 (see Figure 5). The regimes of houses 1 and 2 have been averaged to form the “houses with permanent residents” class. The series of hotels 1 and 2 were also averaged to create a “hotel” regime. The 3rd house series had outliers and was excluded. For each series, the abnormal peaks due to leaks were eliminated.

Figure 5. Typology of drinking water delivery regimes

Houses (Permanent Residents)

- 28 The regime for single-family homes (Fig. 5A) shows greater daily and weekly variability than apartment buildings. The annual average of the unit contributions (382 l / d / accommodation) is also higher than for the apartments, due to the presence of gardens and because certain uses cannot be shared (ex: laundry, central heating). There are periods of non-occupation as well as peaks at Christmas. However, on a monthly scale, there is no marked seasonality and the daily variability remains constant around the annual average. This is due to permanent residence: household demand is maintained throughout the year, except during the holidays.

Houses (Temporary Residents)

- 29 This regime (Fig. 5B) is typical of a single-family chalet in a secondary residence, with a preference for winter occupancy. It shows strong weekly and seasonal variability. The regime coefficients are high ($RC_i > 6$) during the periods of occupation, mainly at Christmas and New Years, as well as at the end of February. Weekly peaks are also observed in mid-winter season (January and March-April). The rest of the year, the values are close to zero, although small peaks ($RC_i \approx 2$) are constantly observed. They are probably due to cleaning out of occupation. The annual average is 290 l / d / accommodation, which is quite high since this type of chalet is unoccupied most of the time.

Hotels

- 30 The regime of a seasonal hotel (Fig. 5C) shows a high seasonality and a clear weekly variability. Hotels have zero RCi in low season (late April to early June and October to November), when closed. In high season, coefficients of around 2 are observed (from July to early September and from December to early April). The weekly variability is mainly observed in mid season (late January and March to early April), when customers come during the weekend. The annual average is 103 l / d / bed. This value should be taken with caution, as it depends on the filling rate of the hotel.

Apartment Blocks (Permanent Residents)

- 31 The regime of an apartment building with permanent residents (Fig. 5D) has very low seasonal variability due to permanent residence regime; the coefficients remain close to the annual average (214 l / d / accommodation) throughout the year ($0.6 < RCi < 1.4$). Furthermore, the daily and weekly variability is low due to the constant demand from permanent residents. Compared to individual dwellings, the daily variability of an apartment building is lower because the water meter averages the contributions of all households and “smooths” the signal.

Apartment Blocks (Temporary Residents)

- 32 This regime (Fig. 5E) represents the mixed buildings typical of tourist resorts, consisting of permanent and temporary accommodation, as well as shops. Most of the accommodation is temporary. Obviously, this regime has a strong seasonality compared to a permanent residential building. Two important peaks are visible in winter: from February to March ($RCi > 2.5$) and at the end of December (Christmas - New Year). There is also a peak from July to August ($RCi > 2$). Two low season periods show low inputs ($RCi \approx 0.5$) from April to June and from September to early December. As with apartments in permanent residence, the daily variability is smoothed by the number of households present in the building. Most of the accommodation being empty almost all year round, the annual average is low (86 l / d / accommodation).

Offices

- 33 The regime of an office building (Fig. 5F) shows a typical “sawtooth” signal, of weekly frequency ($RCi = 0$ on weekends and $1 < RCi < 1.5$ during weekdays). However, on a seasonal scale, the deliveries remain stable around the annual average. This regime is linked to the life cycle of administrative buildings: the occupancy rate is constant during the week but the premises are unoccupied at night and on weekends. For this reason, and also because office water needs are limited (no shower, one meal a day, no laundry), the annual average is very low (12 l / d / work space).

Farms (Barns)

- 34 Drinking water from Megève is used for the watering of dairy cows, once they have come down from the pastures and are sheltered for the winter. This seasonal alternation is observed in the regime (fig. 5G) because the RCi is close to zero from June to October and increases from November to reach a maximum of 2.1 in April. This

regime is interesting because it indicates the period of use of water for watering livestock. We also observe that demand increases in early spring, when temperatures rise and cows need more water.

Analogues Method

- 35 A synthetic signal of the municipal drinking water distribution of Megève was created via the analogues method (Fig. 6). To facilitate graphical interpretation, the cumulative volumes corresponding to each regime are classified from the least seasonal to the most seasonal.

Figure 6. Estimation of drinking water distribution dynamics using the analogues method, based on the water delivery typology

- 36 This reconstruction effectively reproduces the distribution dynamics. Periodic low frequency signals corresponding to seasonal variability and high frequency peaks corresponding to weekly variations are correctly reconstructed. Weekend scale peaks are also reproduced and, like the measured distribution signal, they are more pronounced in winter than in summer. The summer seasonal wave is correctly reconstructed as being less than the winter wave (Christmas holidays, New Year and February included).
- 37 However, with regard to volumes, the analogues method overestimates the distribution during the high seasons and underestimates it during the low seasons. These differences in amplitude come essentially from the sampling mode of the delivery regimes. In Megève, the method was used on a small sample (10 water meters). Although the selection was directed and assisted by the municipal services, the representativeness of the measured regimes certainly causes deviations in seasonal amplitudes. In fact, the analogues method is a technique using averages, with the simplicity but also the disadvantage of being based on sampling. The underestimation of the minimum values can be partly corrected by increasing the proportion of losses on the network. Finally, municipal demand (public fountains, road works, maintenance) is not taken into account and could be added to the distribution signal.

Discussion and Conclusion

- 38 This article provides a detailed assessment of the seasonality of drinking water uses in the Alpine tourist resort of Megève. The main objective is to make up for the lack of water use data.
- 39 The first problem identified being the lack of direct measurements of uses, this study proposes, in addition to the recovery of municipal drinking water distribution data, to

set up a monitoring of the deliveries at the level of the water meter on a sample of buildings. Analysis of the distribution has highlighted the major impact of the presence of temporary residents during peak tourist seasons. A schematic model of the seasonality of drinking water distribution has been constructed (Fig. 4). It complements Marnezy's model (2008) because it presents two types of temporal variability: low frequency (seasonal variability) and high frequency (weekly variability). Then, the intra-annual variations in water supplies were described for the sample of water meters by defining a typology of seasonal patterns, according to the concept of use regime (Calianno *et al.*, 2018). The daily measurement of contributions at the user scale completes the modelling of water distribution management in Megève carried out by Leroy (2015). This detailed analysis produced continuous time series over two and a half years. The advantage of this approach is that these data come from direct and targeted observations. It is a progress compared to previous research on the uses of water in mountain resorts (e.g., Bonriposi, 2013), which are based on proxies or existing data, but of low resolution (temporal and / or Space). This database adds the temporal precision necessary to provide information on the different types of water use on a tourist territory, on the role of temporary visitors in the distribution of drinking water, while previous studies have limited to distribution data or monthly series (Charnay, 2010). Various types of buildings and water use have been described: hotels, single-family homes, apartment buildings, offices and farms. Each shows a distinct seasonal signal which demonstrates the influence i) of the mode of residence (temporary or permanent) on the seasonal variability of low frequency, ii) of the type of habitat (group or single-family housing) on the amplitude of the signal, and iii) weekend visitors on high frequency peaks for temporary residences and hotels. A typology of delivery regimes was constructed to highlight the characteristic temporal signatures (Fig. 5). The particular seasonal patterns observed for offices and the farm show that it is important to define precise categories of water use in order to effectively document the diversity of regimes in an area. This case study, focused on uses, promotes a more detailed inclusion of parameters of water demand in studies modelling the regional water balance (Milano *et al.*, 2013; Collet *et al.*, 2015; Fabre *et al.*, 2015). This study also adds an additional step in terms of time scale (daily regimes) and spatial resolution (at the user and building scales) compared to studies limiting the determinants of demand to the variation of the population (Soboll and Schmude, 2011; Buytaert and de Bièvre, 2012).

- 40 The second problem identified being the low availability of water use data, this study proposes the analogues method, where the typologies of delivery regimes coming from the monitoring are used as patterns to reconstruct the seasonality of the municipal drinking water distribution (Fig. 6). The method correctly reproduces the temporal variability of the distribution in Megève. This indicates a good representativeness of the selected typology, even if it is based on a small sample ($n = 10$). In terms of volume, this method is still imprecise, but could be improved by increasing the sample size. Such results could be associated with the model developed by Leroy (2015), which presented a precise estimate of the volumes of drinking water distributed in Megève, although with less precision of the temporal variability. That said, the main objective of the analogues method is to reproduce the seasonality of the distribution on the basis of a set of data that is easy to collect, so that water managers and stakeholders can put it into practice. This technique can be applied to any territory that does not have water use data, or for urban planning, by means of a new monitoring campaign on the

territory (Calianno and Reynard, 2019). The advantage is that it is necessary to equip only a small number of water meters, provided that the sample is selected in close collaboration with local managers. This method would also be a useful tool for comparing the seasonal nature of the uses of drinking water between the various tourist resorts, the demand for water mainly depending on the rates of capacity in second homes and tourist accommodation. In addition, based on a sampling of “patterns” measured in situ and reproducing the particular dynamics of each type of user, this technique allows to go further than estimates based solely on demography (in liters / day / person) and can just as easily be applied in cities and territories with permanent populations.

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ABSTRACTS

Few of the integrated water management surveys or water offer-demand models include a description of the seasonality of demand with sufficiently fine time steps (monthly and lower). The analogues method was developed in this study with as a case study the tourist resort of Megève (Haute-Savoie, France), presenting a strong seasonal variability in the demand for drinking water. The method is intended for decision-makers and urban planners, because it makes it possible to predict the seasonality of drinking water distribution in Alpine regions where data on water use is rarely available. It involves monitoring on a sample of domestic drinking water meters with a daily resolution, to identify the different demand regimes and use them as “patterns” to reproduce the municipal distribution signal.

Analysis of the distribution of drinking water has highlighted two types of variability: high frequency (weekly) and low frequency (seasonal). The monitoring underlined the influence of the type of building and the permanence of the habitat on the drinking water distribution regimes. Finally, the analogues method is considered to be effective in reproducing the low and high frequency variability of the distribution. The size and representativeness of the user sample are the most important factors to be taken into account in its implementation.

INDEX

Mots-clés: Monitoring ; drinking water; distribution seasonality ; mountain tourist resorts ; analogues method

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