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*Cover: proglacial lake below the Glacier de la Sorne in late September 2025. The lake did not exist when monitoring began in 2011.*

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# ABOUT THE BULLETIN

## AIMS AND SCOPE

The *Bulletin of the Alpine Water Research Institute* publishes research articles, short communications and reviews on the hydrology, glaciology and aquatic ecology of mountain regions, with an emphasis on the Alps. It addresses researchers as well as practitioners in water management, hydropower and environmental administration. Articles are peer-reviewed by at least two independent referees; short communications by one referee and an editor.

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Figures should be supplied as vector graphics or as images with a resolution of at least 300 dpi. Units follow the International System; glacier mass balance is given in metres of water equivalent (m w.e.). References are cited by number in order of appearance and must include a DOI where available.

Data underlying published results must be deposited in a recognised repository, and the data availability statement must give the identifier. Authors retain copyright and grant the institute a licence to publish.

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EDITORIAL

# Water towers under pressure

RUEDI ALBRECHT
*Director, Alpine Water Research Institute, Montvallier*
Published 30 October 2026 · doi:10.5555/awri.12.3.001

When the first measurement stakes were drilled into the Glacier de la Sorne in the autumn of 2010, the proglacial lake on the cover of this issue did not exist. Fifteen years later it covers almost four hectares, and the glacier tongue that once filled its basin has retreated by more than 600 metres. The long series presented by Fournier and colleagues in this issue documents that change year by year: the glacier has lost on average 1.19 metres of water equivalent per year, and 2022 and 2023 were the two most negative years in the record.

The Alps are often called the water towers of Europe. The image is apt, but it hides an uncomfortable truth: a water tower is only useful as long as it is refilled. Snow and ice store winter precipitation and release it in summer, when demand from agriculture, hydropower and ecosystems is highest. As glaciers shrink and the snowpack melts earlier, this seasonal storage is being lost. Valsecchi and co-authors show that snowmelt onset at 2 250 metres in the Montvallier catchment now occurs about five days earlier per decade than in the 1980s, and that August stream temperatures have risen by almost two degrees.

These changes are not only a scientific concern. Hydropower operators, municipalities and fishery authorities have to adapt reservoir operation, water supply and habitat management to a regime that is still changing. The short communication by Pfammatter, Rochat and Kälin is an example of the cooperation this requires: it reports on the first fully monitored sediment flushing of the Lac de Sorne reservoir, carried out by Hydro Val-Sorne under conditions agreed with the cantonal authorities and accompanied by our aquatic ecology group.

With this issue we also introduce a new feature. On page 16, seven colleagues from partner institutes describe glaciers and rivers in their own languages, from Arabic to Hindi. Water connects mountain regions across the world, and so does the research that tries to understand it.

I thank the authors, the reviewers and our editorial team, and wish you an inspiring read.

RUEDI ALBRECHT

RESEARCH ARTICLE · GLACIER MASS BALANCE

# Fifteen years of mass balance on the Glacier de la Sorne, 2011–2025

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ABSTRACT

We present the glaciological mass balance of the Glacier de la Sorne (3.1 km$^2$ in 2025) for the hydrological years 2011 to 2025, based on 38 ablation stakes and annual snow-pit and probing surveys. The mean annual balance was -1.19 m w.e. a$^{-1}$, and the cumulative loss reached 17.9 m w.e. The annual balance is closely related to the mean summer air temperature at Les Ecots ($r^2$ = 0.98; -0.95 m w.e. per °C). Since 2022 the equilibrium line has been close to or above the highest part of the glacier, so that the glacier no longer has a persistent accumulation area. Glacier melt contributed 31% of August runoff into the Lac de Sorne reservoir on average.

*Keywords: glacier mass balance; equilibrium-line altitude; degree-day model; glacier runoff; Alps*

RÉSUMÉ

Nous présentons le bilan de masse glaciologique du glacier de la Sorne pour les années hydrologiques 2011 à 2025, établi à partir de 38 balises d'ablation et de mesures annuelles de la neige. Le bilan annuel moyen est de -1.19 m d'équivalent en eau par an et la perte cumulée atteint 17.9 m. Le bilan dépend étroitement de la température estivale. Depuis 2022, la ligne d'équilibre se situe près du sommet du glacier, qui n'a plus de zone d'accumulation durable.

ZUSAMMENFASSUNG

Wir stellen die glaziologische Massenbilanz des Glacier de la Sorne für die hydrologischen Jahre 2011 bis 2025 vor, gestützt auf 38 Ablationspegel und jährliche Schneeschachtmessungen. Die mittlere Jahresbilanz betrug -1.19 m Wasseräquivalent pro Jahr, der kumulierte Verlust 17.9 m. Die Bilanz hängt eng mit der Sommertemperatur zusammen. Seit 2022 liegt die Gleichgewichtslinie nahe dem höchsten Punkt des Gletschers; ein dauerhaftes Akkumulationsgebiet besteht nicht mehr.

RIASSUNTO

Presentiamo il bilancio di massa glaciologico del ghiacciaio della Sorne per gli anni idrologici dal 2011 al 2025, basato su 38 paline ablatometriche e su rilievi annuali del manto nevoso. Il bilancio annuo medio è stato di -1.19 m di equivalente in acqua all'anno e la perdita cumulata di 17.9 m. Il bilancio dipende strettamente dalla temperatura estiva. Dal 2022 la linea di equilibrio si trova vicino alla quota massima del ghiacciaio, che non ha più una zona di accumulo permanente.

RESUMAZIUN

Nus preschentain la bilantscha da massa glaciologica dal glatscher da la Sorne per ils onns idrologics 2011 fin 2025, fundada sin 38 pals d'ablaziun e sin mesiraziuns annualas da la naiv. La bilantscha annuala media era -1.19 m equivalent d'aua per onn, la perdita cumulada 17.9 m. La bilantscha dependa fermamain da la temperatura da la stad. Dapi il 2022 sa chatta la lingia d'equiliber datiers dal punct il pli aut dal glatscher, che n'ha nagina zona d'accumulaziun permanenta pli.

## 1 INTRODUCTION

Glaciers in the European Alps have lost about 40% of their volume since 2000, with exceptional losses in 2022 and 2023.[1] Long glaciological mass-balance series are essential to attribute these changes to their climatic drivers, to calibrate models and to quantify the contribution of glacier melt to runoff. In the western Alps, however, only a few glaciers smaller than 5 km$^2$ have been measured continuously for more than a decade, although small glaciers make up most of the glacier number and react fastest.

The Glacier de la Sorne drains into the Lac de Sorne reservoir, which feeds the power houses of Les Ecots and Vernay. Since 2011, the Alpine Water Research Institute has measured its mass balance in cooperation with the reservoir operator Hydro Val-Sorne. This paper presents the complete series for 2011 to 2025, analyses its relation to summer temperature and estimates the contribution of glacier melt to inflow into the reservoir.

## 2 STUDY SITE AND DATA

The Glacier de la Sorne (46.07° N, 7.38° E) extends from 3 450 m to 2 350 m a.s.l. on the north-east flank of the Sorne massif. Its area decreased from 4.2 km$^2$ in 2011 to 3.1 km$^2$ in 2025. The glacier is largely debris-free except for the lowest 400 m of the tongue, where a medial moraine has widened since 2018. Meteorological data are taken from the automatic station at Les Ecots (1 480 m), operated by Hydro Val-Sorne since 1987, about 6 km from the glacier front.

Between 2011 and 2025 the glacier tongue retreated by 620 m, and a proglacial lake of 3.8 ha formed in the overdeepening exposed after 2016 (Figure 1). The upper part of the glacier, above 3 100 m, has thinned by 8 to 12 m but has kept its extent, so that the glacier is becoming shorter and more compact. Two small tributary ice bodies on the western flank separated from the main glacier in 2019 and 2022 and are no longer included in the glacier-wide balance.

[1] Volume change estimates are based on repeated digital elevation models and are summarised in the national glacier monitoring reports; see [3] and [5].

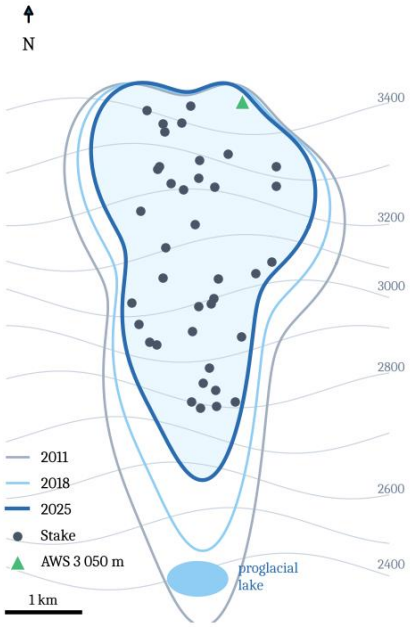



Figure 1. Glacier de la Sorne: outlines in 2011, 2018 and 2025, ablation stakes and the automatic weather station installed in 2026. Contours every 100 m.



Ablation was measured at 38 stakes distributed over eleven elevation bands of 100 m. Winter accumulation was determined in late April or early May by snow probing at 150 to 220 points and density measurements in three snow pits. Annual balances refer to the hydrological year from 1 October to 30 September and were corrected to fixed dates using a degree-day model (Section 3). Uncertainties were estimated at ±0.25 m w.e. for the annual glacier-wide balance, following the error propagation of reference [2].

## 3 METHODS

The glacier-wide balance $B_a$ is the area-weighted mean of the specific balances $b_i$ of the elevation bands:

$$B_a = \frac{1}{S}\sum_{i=1}^{n} b_i s_i \qquad (1)$$

where $s_i$ is the area of band $i$ and $S = \sum s_i$ the total glacier area, updated annually from orthophotos. Melt between survey dates and the fixed date was computed with an enhanced degree-day model,

$$M = \begin{cases} (f_M + r_{\mathrm{snow/ice}} I)T, & T > T_0 \\ 0, & T \le T_0 \end{cases} \qquad (2)$$

with daily mean air temperature $T$ extrapolated with a lapse rate of −0.0065 °C m$^{-1}$, potential clear-sky radiation $I$, a melt factor $f_M$ = 1.8 mm d$^{-1}$ °C$^{-1}$ and radiation factors $r_{\mathrm{snow}}$ = 0.0006 and $r_{\mathrm{ice}}$ = 0.0011 mm m$^2$ W$^{-1}$ d$^{-1}$ °C$^{-1}$, calibrated against stake readings from 2011 to 2015. The threshold temperature $T_0$ was set to 0 °C.

The contribution of glacier melt to runoff was estimated as the volume of ice and firn lost in excess of the annual snow cover, $Q_{\mathrm{gl}} = \frac{S\cdot(-B_a)\cdot\rho_w}{\rho_w\cdot\Delta t}$, distributed over the melt season according to the degree-day model and compared with the measured inflow into the reservoir.

### 3.1 Geodetic validation and uncertainty

The glaciological series was compared with geodetic balances derived from airborne laser scanning in 2011 and from photogrammetric surface models in 2015, 2020 and 2025, converted to water equivalent with a density of 850 ± 60 kg m$^{-3}$. The two methods agree within their uncertainties in all three periods (Table 1), so no calibration of the glaciological series was necessary.

Table 1. Mean annual balance (m w.e. a$^{-1}$) from the glaciological and geodetic methods.

| Period | Glaciol. | Geodetic | Diff. |
|---|---|---|---|
| 2011–2015 | −0.74 | −0.79 | 0.05 |
| 2016–2020 | −1.22 | −1.15 | −0.07 |
| 2021–2025 | −1.62 | −1.70 | 0.08 |

The uncertainty of the annual glacier-wide balance combines the point measurement error, the spatial interpolation with an effective number of independent points, the snow density and the glacier area:

$$\sigma_{B_a} = \sqrt{\frac{\sigma_b^2}{n_{\mathrm{eff}}} + \sigma_\rho^2 + \sigma_S^2} \qquad (3)$$

With $\sigma_b$ = 0.20 m w.e., $n_{\mathrm{eff}}$ = 9, $\sigma_\rho$ = 0.14 m w.e. and $\sigma_S$ = 0.05 m w.e., 0 yields $\sigma$ = 0.18 m w.e., slightly lower than the conservative value of 0.25 m w.e. used in the figures.

## 4 RESULTS

### 4.1 Annual and cumulative balance

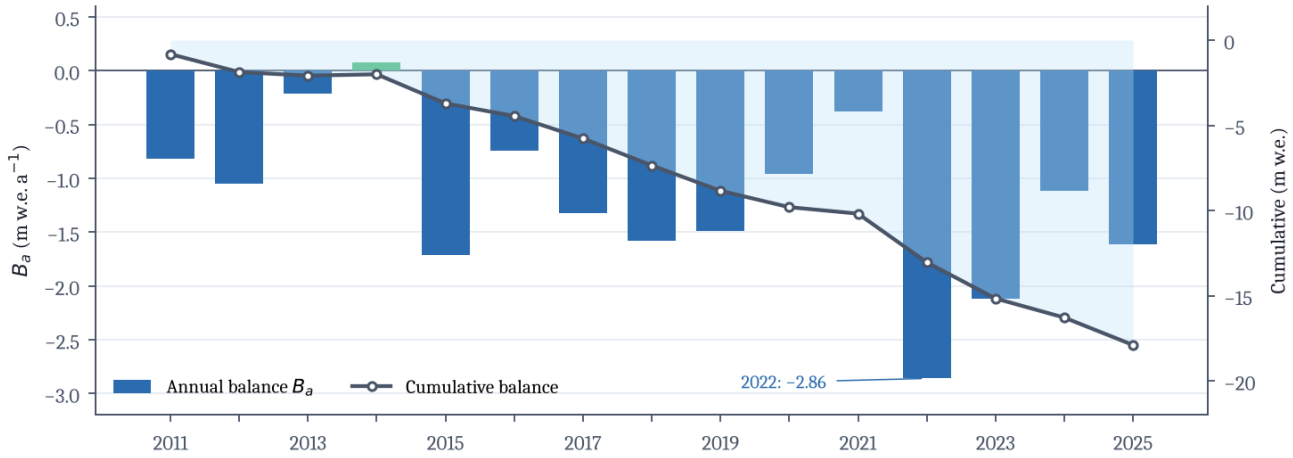



Figure 2. Annual glacier-wide balance $B_a$ and cumulative balance of the Glacier de la Sorne, 2011–2025. The mean annual balance was -1.19 m w.e.; only 2014 was slightly positive.

The annual balance was negative in fourteen of the fifteen years (Figure 2). The mean balance was -1.19 m w.e. a$^{-1}$ and the cumulative balance -17.9 m w.e., equivalent to an average thinning of about 20 m. The only positive year, 2014, followed a winter with 140% of the mean snow accumulation and a cool, overcast August. The most negative balance, −2.86 m w.e. in 2022, resulted from a combination of a thin snowpack, Saharan dust deposition in March that lowered the albedo, and a hot summer.

Winter balances varied between 0.92 and 1.83 m w.e. and showed no significant trend. Summer balances, in contrast, became more negative by 0.11 m w.e. per year (Table 2). The interannual variability of the annual balance is therefore dominated by the summer balance, as on most Alpine glaciers.

Table 2. Seasonal balances (m w.e.), equilibrium-line altitude (ELA, m a.s.l.) and accumulation-area ratio (AAR) in selected years.

| Year | $B_w$ | $B_s$ | $B_a$ | ELA | AAR |
|---|---|---|---|---|---|
| 2014 | 1.62 | −1.54 | 0.08 | 2 890 | 0.62 |
| 2015 | 1.18 | −2.89 | −1.71 | 3 240 | 0.18 |
| 2018 | 1.71 | −3.29 | −1.58 | 3 210 | 0.21 |
| 2020 | 1.44 | −2.40 | −0.96 | 3 080 | 0.35 |
| 2022 | 0.92 | −3.78 | −2.86 | > 3 450 | 0.00 |
| 2023 | 1.21 | −3.33 | −2.12 | 3 360 | 0.08 |
| 2024 | 1.66 | −2.78 | −1.12 | 3 120 | 0.31 |
| 2025 | 1.12 | −2.73 | −1.61 | 3 200 | 0.15 |
| **Mean 2011–2025** | **1.37** | **−2.56** | **−1.19** | **3 180** | **0.26** |

### *4.2 Relation to summer temperature*

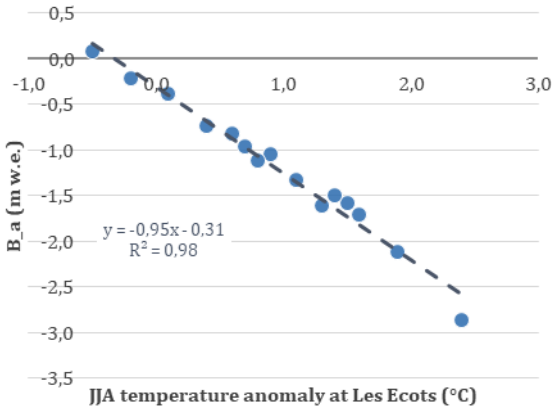



Figure 3. Annual balance versus June–August temperature anomaly (relative to 1991–2020) at Les Ecots, with least-squares fit ($r^2$ = 0.98).

The annual balance is strongly correlated with the June–August temperature anomaly (Figure 3). A linear regression gives a sensitivity of -0.95 m w.e. per °C ($r^2$ = 0.98, $n$ = 15). Adding winter precipitation as a second predictor improves the fit only marginally, because the winter balance is partly captured by the radiation term in summer through the timing of snow-free conditions.[2]

### *4.3 Equilibrium line and balance profile*

The equilibrium-line altitude rose from 2 890 m in 2014 to 3 200 m in 2025 and was above the summit in 2022 (Figure 4). The vertical balance gradient steepened from 0.31 to 0.49 m w.e. per 100 m, mainly because melt on the lower tongue increased. The accumulation-area ratio, 0.62 in 2014, has not exceeded 0.35 since 2019; the steady-state value for Alpine glaciers is about 0.6. The glacier is therefore far from equilibrium with the present climate and will continue to retreat even without further warming.

[2] The partial correlation between winter precipitation at Les Ecots and the annual balance, controlling for summer temperature, is 0.31 (p = 0.27).

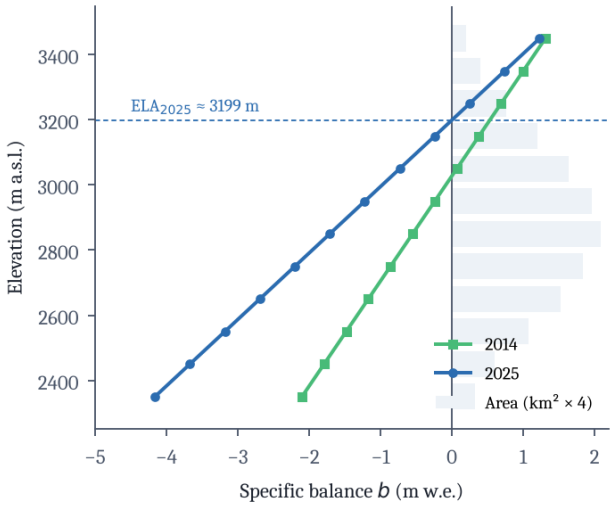



Figure 4. Specific balance as a function of elevation in 2014 and 2025, with the area of each 100 m band.

### 4.4 Contribution to reservoir inflow

Glacier melt (ice and firn) contributed on average 31% of the inflow into the Lac de Sorne in August and 12% over the whole year (Figure 5). In 2022 the August contribution reached 47%. Because the glacier area is shrinking, the absolute melt volume has not increased since 2015 despite more negative specific balances, which suggests that "peak water" has been reached or passed in this catchment.

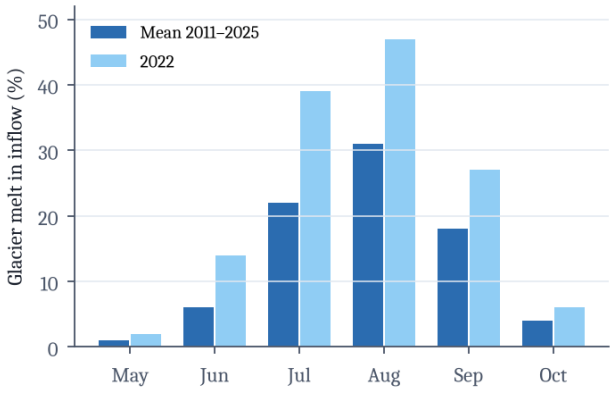



Figure 5. Share of glacier melt (ice and firn) in monthly inflow into the Lac de Sorne.

The share of glacier melt is highest in dry, warm summers, when it partly compensates for the lack of rain. In 2022 glacier melt delivered an estimated 9.6 million m³ of water to the reservoir between July and September, about one third of the inflow needed to reach full supply level by the end of the season.

### 4.5 Comparison with neighbouring glaciers

Four smaller glaciers in the massif have been surveyed geodetically since 2011. Their mean balances range from −0.98 to −1.46 m w.e. a⁻¹ and are closely related to their median elevation (Table 3). The Glacier du Mont Sorne, the highest of the group, lost least, while the Glacier de la Clusaz, which no longer reaches above 3 000 m, lost almost one third of its area and split into three parts in 2023.

Table 3. Glaciers of the Sorne massif: area in 2025 (km²), median elevation (m a.s.l.) and mean annual balance 2011–2025 (m w.e. a⁻¹).

| Glacier | Area | Median z | $\bar{B}_a$ |
|---|---|---|---|
| de la Sorne | 3.10 | 2 960 | −1.19 |
| du Mont Sorne | 1.42 | 3 120 | −0.98 |
| des Ecots | 0.87 | 2 890 | −1.31 |
| de Vernay | 0.64 | 2 840 | −1.38 |
| de la Clusaz | 0.21 | 2 760 | −1.46 |

### 4.6 Albedo and dust deposition

Mean August albedo of the ablation area, derived from satellite images, decreased from 0.38 in 2011–2015 to 0.27 in 2021–2025. Saharan dust was deposited on the snowpack in March 2022 and in February 2024; in both years the snow surface darkened earlier in summer and the snowline rose about three weeks ahead of the long-term mean. Using the radiation term of 0, we estimate that the lower albedo increased melt by 0.25 m w.e. in 2022, about 9% of the annual loss.

## 5 DISCUSSION AND CONCLUSIONS

The mass-balance sensitivity of −1.1 m w.e. per °C found here is at the upper end of values reported for Alpine glaciers [1, 4], consistent with the small size and low elevation range of the Glacier de la Sorne. With an accumulation-area ratio persistently below 0.35, the glacier is likely to lose most of its remaining volume by the 2060s under a moderate emission scenario. For the reservoir operator, the decline of glacier melt implies lower late-summer inflow and a growing importance of the autumn and spring snowmelt peaks for reservoir filling.

Two limitations should be noted. First, the stake network was designed for the glacier of 2011 and is sparse on the upper plateau, where most of the remaining ice is now located; three additional stakes were installed above 3 200 m in 2023. Second, the expanding debris cover on the lowest part of the tongue reduces melt locally by up to 40%, an effect that the degree-day model represents only through the empirical radiation factor.

For water management, the results imply that the buffering role of the glacier in hot, dry summers is declining. Reservoir operation that relies on late-summer glacier inflow to reach full supply level will need to shift towards earlier filling during the snowmelt peak in May and June, as already practised by Hydro Val-Sorne since 2023.

The series will be continued, and we plan to complement the stake network with repeated drone surveys of the tongue to capture the effect of the expanding debris cover.

**Acknowledgements.** We thank the field assistants of the AWRI glaciology group and the staff of Hydro Val-Sorne at Les Ecots for logistical support. Data are available from the AWRI data portal (doi:10.5555/awri.data.sorne-mb).

## APPENDIX A ELEVATION BANDS IN 2025

Area, number of stakes and specific balance of the 100 m elevation bands used in 0 for 2025. The area-weighted mean of the band balances equals the glacier-wide balance of −1.61 m w.e.

Table 4. Elevation bands of the Glacier de la Sorne in 2025.

| Band (m) | Area (km²) | Stakes | b (m w.e.) |
|---|---|---|---|
| 2 300–2 400 | 0.07 | 4 | −4.16 |
| 2 400–2 500 | 0.14 | 4 | −3.67 |
| 2 500–2 600 | 0.25 | 5 | −3.18 |
| 2 600–2 700 | 0.35 | 5 | −2.69 |
| 2 700–2 800 | 0.42 | 4 | −2.20 |
| 2 800–2 900 | 0.47 | 4 | −1.71 |
| 2 900–3 000 | 0.45 | 3 | −1.22 |
| 3 000–3 100 | 0.37 | 3 | −0.73 |
| 3 100–3 200 | 0.27 | 2 | −0.24 |
| 3 200–3 300 | 0.17 | 2 | 0.25 |
| 3 300–3 400 | 0.09 | 1 | 0.74 |
| 3 400–3 500 | 0.05 | 1 | 1.23 |
| **Glacier** | **3.10** | **38** | **−1.61** |

**Data availability.** Stake readings, snow-pit data and annual balances are available from the AWRI data portal (doi:10.5555/awri.data.sorne-mb). Meteorological data from Les Ecots are provided by Hydro Val-Sorne on request.

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SHORT COMMUNICATION · RESERVOIR SEDIMENT

# Sediment flushing of the Lac de Sorne: suspended sediment and benthic recovery downstream

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## ABSTRACT

In June 2025 the bottom outlet of the Barrage de la Sorne was opened for 18 hours to flush about 78 000 t of fine sediment from the Lac de Sorne. Suspended sediment concentration (SSC) peaked at 15 g L$^{-1}$ 1.2 km downstream and fell below 1 g L$^{-1}$ within 60 hours. Macroinvertebrate density decreased by 81% at the nearest station but recovered to 74% of pre-flushing values after three months.

## ZUSAMMENFASSUNG

Im Juni 2025 wurde der Grundablass der Staumauer de la Sorne während 18 Stunden geöffnet, um rund 78 000 t Feinsediment aus dem Lac de Sorne zu spülen. Die Schwebstoffkonzentration erreichte 1,2 km unterhalb 15 g L$^{-1}$. Die Dichte des Makrozoobenthos sank um 81 % und erholte sich innert drei Monaten auf 74 % des Ausgangswerts.

## BACKGROUND

Reservoirs in glaciated catchments trap large amounts of fine sediment. The Lac de Sorne, impounded in 1964, loses about 0.3% of its storage volume each year, and sediment deposits near the intake threaten the operation of the bottom outlet. Flushing, the release of sediment through the bottom outlet during a controlled drawdown, restores storage and keeps the outlet functional, but the sudden sediment load can harm downstream ecosystems.

In 2025, Hydro Val-Sorne carried out the first flushing since 2009 under a monitoring programme defined with the cantonal environmental authority. Here we report suspended sediment concentrations and the response of benthic macroinvertebrates at three stations.

## STUDY SITE

The Lac de Sorne is impounded by a 112 m high arch dam completed in 1964. At full supply level (1 985 m) the reservoir stores 48 million m$^3$ and covers 1.9 km$^2$. Its catchment of 38 km$^2$ was 24% glacierised in 1973 and is 8% glacierised today. The mean annual sediment inflow, estimated from repeated bathymetric surveys, is 46 000 t, most of it fine silt from glacial abrasion delivered between June and September.

The bottom outlet, two 1.6 m gates at 1 921 m, was partly blocked by deposits after a flood in 2024. The flushing was planned for June, when the natural discharge and turbidity of the Sorne are high and downstream aquatic life is adapted to elevated sediment loads (Table 5).

Table 5. Key data of the 2025 flushing operation.

| Parameter | Value |
|---|---|
| Start of drawdown | 15 Jun, 08:00 |
| Outlet open | 17 Jun, 06:00–24:00 |
| Drawdown | 31 m |
| Peak outflow | 86 m$^3$ s$^{-1}$ |
| Flushed sediment | 78 300 t |
| Refilling to FSL | 12 Jul |

**How does a reservoir flush work?**
The reservoir is drawn down until the water level approaches the bottom outlet. When the gates are opened, the inflowing river cuts a channel through the deposits and carries fine sediment through the outlet. The operation ends when the outflow clears or when the agreed limits for duration or concentration are reached; the reservoir is then refilled.

## METHODS

Turbidity was recorded every 5 minutes at station S1 upstream of the reservoir and at S2 and S3, 1.2 and 6.8 km downstream of the dam. Turbidity $T$ (FNU) was converted to SSC with a power-law rating curve fitted to 64 filtered samples,



Figure 6. Turbidity samples were calibrated against filtered SSC in the AWRI laboratory.

$$C = aT^{b},\ a = 0.0021,\ b = 1.07(4)$$

and the sediment load was obtained by integrating the product of discharge $Q$ and concentration $C$ over the event, $L = \int_{t_0}^{t_1} Q(t)C(t)\,\mathrm{d}t$. Macroinvertebrates were sampled with a Surber sampler (0.09 m$^2$, six replicates) before and 1 week, 1 month and 3 months after the flushing.

## RESULTS

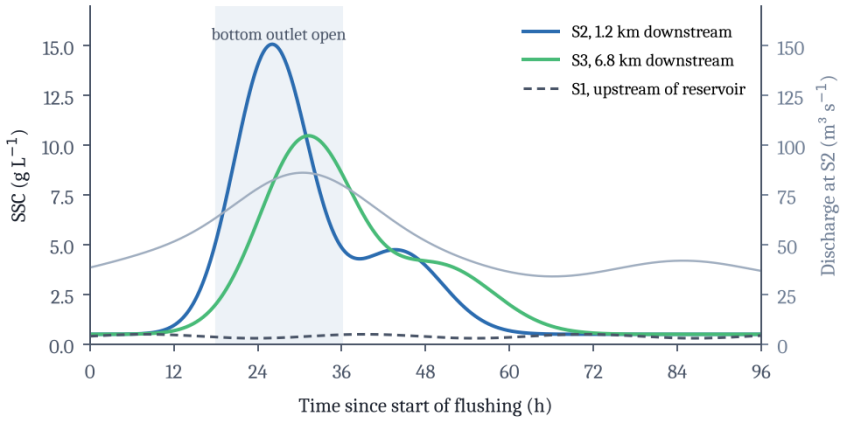



Figure 7. Suspended sediment concentration at the three stations and discharge at S2 during the flushing of 17–20 June 2025.

The bottom outlet was opened on 17 June 2025 at 06:00 for 18 hours, while the reservoir level was lowered by 31 m. SSC at S2 rose to 15.0 g L$^{-1}$ after 26 hours and showed a second, smaller peak when the outlet was closed and the remaining deposits were eroded by the inflow (Figure 7). At S3 the peak was attenuated to 10.3 g L$^{-1}$. The integrated load at S2 was 78 300 t, about 60% of the volume estimated from bathymetric surveys before and after the event.[3]

Table 6. Macroinvertebrate density (individuals m$^{-2}$, mean of six samples).

| | S1 | S2 | S3 |
|---|---|---|---|
| Before | 2 140 | 1 860 | 2 010 |
| 1 week | 2 090 | 350 | 780 |
| 1 month | 2 210 | 910 | 1 420 |
| 3 months | 2 060 | 1 380 | 1 840 |

Dissolved oxygen at S2 did not fall below 7.8 mg L$^{-1}$, and the ammonium concentration peaked at 0.42 mg L$^{-1}$, well below the threshold for acute toxicity to fish at the observed temperature of 6 to 8 °C. Repeated bathymetric surveys showed that the deposit in front of the bottom outlet was removed over a length of 900 m and that the bed was lowered by up to 8 m (Figure 8).

Macroinvertebrate density at S2 fell by 81% one week after the flushing and recovered to 74% of the initial value after three months (Table 6). Recovery was faster at S3, where tributaries supplied colonists. Mayflies and stoneflies recovered more slowly than chironomids.

Brown trout were electrofished at S2 and S3 in May and September 2025. The density of trout older than one year decreased by 35% at S2 but not at S3; no dead fish were found during the event, which we attribute to the fish rescue at three tributary mouths before the flushing and to the high discharge, which shortened the duration of peak concentrations.

## DISCUSSION

The peak SSC observed at S2 is within the range reported for comparable flushing operations in Alpine reservoirs, but the duration of concentrations above 5 g L$^{-1}$, 21 hours, was shorter than in most earlier events [1]. The second concentration peak after the closure of the outlet, caused by erosion of the remaining deposits by the inflowing river, accounted for 18% of the load and should be considered in future planning.

The recovery of macroinvertebrates within three months is consistent with the rapid recolonisation from undisturbed tributaries and from drift reported for other glacier-fed rivers [2]. Taxa with a long aquatic life cycle, such as large stoneflies, may need a full year to recover; we will repeat the sampling in June 2026.

## GRAIN SIZE OF THE FLUSHED SEDIMENT

Laser diffraction of 24 samples from S2 gave a median grain size $d_{50}$ of 12 µm at the concentration peak and of 7 µm in the receding limb; the sand fraction (> 63 µm) never exceeded 5%. Most of the flushed material was therefore transported as wash load and was not deposited in the river bed between S2 and S3, except in two pools where up to 4 cm of silt were found one week after the event.

Table 7. Monitoring stations.

| Station | km | z (m) |
|---|---|---|
| S1 Pont du Lac | −2.4 | 2 010 |
| S2 Les Ecots | 1.2 | 1 455 |
| S3 Vernay | 6.8 | 1 160 |

## MONITORING RECOMMENDATIONS

Based on the 2025 experience, we recommend the following for future flushing operations at the Lac de Sorne:

- continuous turbidity measurement at S2 and S3 with redundant sensors and a sampling programme of at least two samples per hour during the first 30 hours;
- bathymetric surveys immediately before and after the event to close the sediment budget;

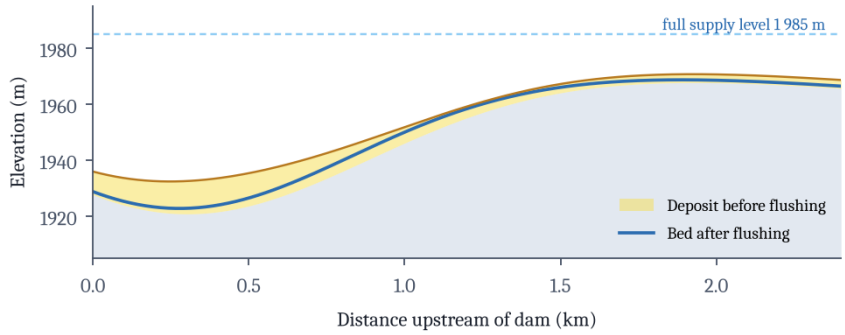



Figure 8. Longitudinal profile of the reservoir bed upstream of the dam before and after the flushing.

[3] The difference is attributed to coarse sediment that was remobilised within the reservoir but did not pass the bottom outlet.

- macroinvertebrate sampling at least one week, one month, three months and one year after the event;
- communication with anglers, municipalities and drinking-water suppliers at least two weeks in advance.

## IMPLICATIONS

The flushing restored about 0.6% of the reservoir volume and the full function of the bottom outlet. The ecological impact was severe but temporary. Earlier flushing in late spring, at higher natural discharge and turbidity, and shorter, more frequent events are likely to reduce the impact further; these options will be tested in 2027.

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RESEARCH ARTICLE · SNOW AND STREAM TEMPERATURE

# Earlier snowmelt and warmer streams in the Montvallier catchment

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ABSTRACT

Using forty years of snow and discharge data and thirty years of stream temperature records, we show that snowmelt onset at 2 250 m in the Montvallier catchment has advanced by 5.0 days per decade since 1986. Mean August stream temperature at the city intake rose by 1.9 °C between 1996 and 2025, with the strongest warming in July and August, when snowmelt no longer cools the river.

RIASSUNTO

Sulla base di quarant'anni di dati nivometrici e idrologici mostriamo che l'inizio della fusione nivale a 2 250 m nel bacino di Montvallier è anticipato di 5,0 giorni per decennio dal 1986. La temperatura media di agosto del torrente è aumentata di 1,9 °C tra il 1996 e il 2025.

## 1 INTRODUCTION

Snow acts as a seasonal reservoir that delays runoff from winter to late spring and summer. In mountain catchments without large glaciers, the timing of snowmelt therefore determines when rivers carry most water and how cold they remain in early summer. The city of Montvallier draws 40% of its drinking water from the Sorne below the gorge of La Clusaz, and its water service has monitored stream temperature at the intake since 1996.

We combine these records with snow observations at the Col de Vernay station (2 250 m) to quantify trends in snowmelt timing and stream temperature and to assess their consequences for water supply.

### 1.1 Study area



The Sorne catchment upstream of the Montvallier intake covers 112 km² between 640 and 3 450 m a.s.l., with a mean elevation of 1 820 m. Forest covers 31% of the area, alpine meadows 38% and rock and scree 23%; glaciers occupy less than 5%. Discharge has been measured at La Clusaz since 1984, and snow depth and snow water equivalent at the Col de Vernay station since 1985. The intake abstracts on average 180 L s⁻¹, which is treated by ultrafiltration before distribution to 41 000 inhabitants.

## 2 DATA AND METHODS

Snowmelt onset was defined as the first day after 1 March on which the snow depth decreased on at least five of seven consecutive days and the snow water equivalent began a sustained decline. Trends were estimated with the Theil–Sen estimator,

$$\beta = \operatorname{median}\left(\frac{x_j - x_i}{j - i}\right),\ i < j \qquad (5)$$

and their significance with the Mann–Kendall test, using the statistic

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \qquad (6)$$

which is approximately normally distributed with variance $\operatorname{Var}(S) = \frac{n(n-1)(2n+5)}{18}$ in the absence of ties. Stream temperature was measured every 10 minutes with two redundant sensors; gaps shorter than three days (1.4% of the record) were filled by linear regression with air temperature.

## 3 RESULTS

Snowmelt onset advanced from around day 128 (8 May) in the late 1980s to day 109 (19 April) in the 2020s (Figure 9). The Theil–Sen slope is −5.0 days per decade (Mann–Kendall $p < 0.001$). The trend is driven mainly by warmer springs; maximum snow water equivalent decreased by only 6% per decade, which is not significant.

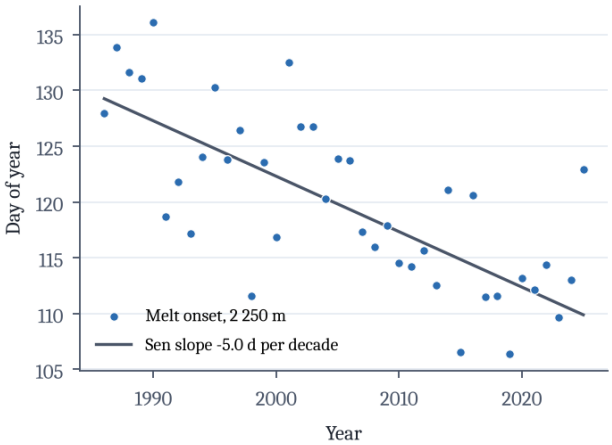



Figure 9. Day of snowmelt onset at Col de Vernay (2 250 m), 1986–2025, with Theil–Sen trend.

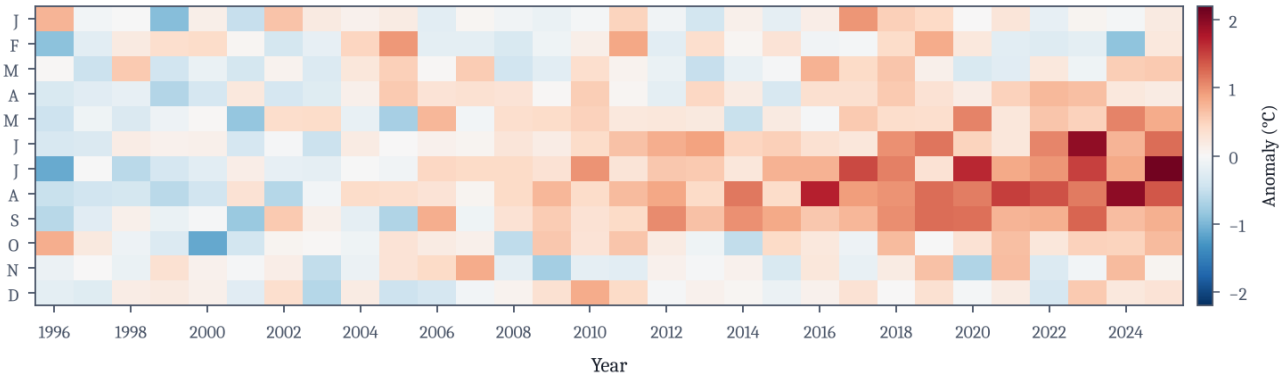



Figure 10. Monthly stream-temperature anomaly at the Montvallier intake relative to 1996–2010. Warming is strongest from June to September.

Stream temperature at the intake increased in all months, but most strongly from June to September (Figure 10). The mean August temperature rose by 1.9 °C between 1996 and 2025, compared with an increase in August air temperature of 1.6 °C at Montvallier. The difference reflects the declining share of cold snowmelt water in the river in late summer. Days with a daily maximum above 12 °C, the threshold above which the water service increases disinfection, rose from 4 to 23 per year.

### 3.1 Discharge regime

The earlier snowmelt has shifted the seasonal peak of discharge from June to May (Figure 11). Mean discharge in April and May increased by 71% and 36%, while July and August flows decreased by 32% and 20%. Annual discharge did not change significantly, which indicates that the shift reflects a redistribution of runoff in time rather than a change in precipitation.

> "In early August, the river at the intake is now as warm as it used to be in the hottest week of the year."
> C. VALSECCHI

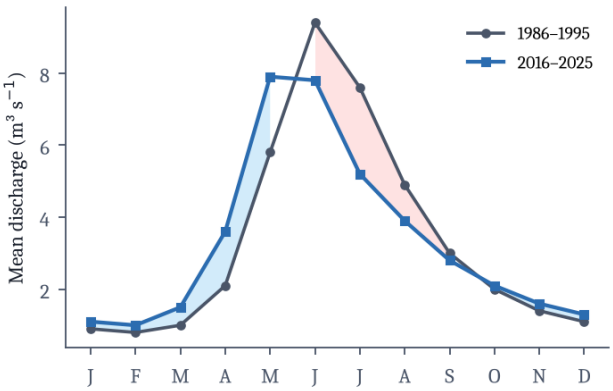



Figure 11. Mean monthly discharge of the Sorne at La Clusaz in 1986–1995 and 2016–2025.

### 3.2 Air and water temperature

The relation between weekly mean air temperature $T_a$ and stream temperature $T_w$ was described with the non-linear logistic model of [1],

$$T_w = \mu + \frac{\alpha - \mu}{1 + e^{\gamma(\beta - T_a)}} \quad (7)$$

where α is the upper and μ the lower bound of stream temperature, β the air temperature at the inflection point and γ the steepness of the curve. The model was fitted separately for 1996–2005 and 2016–2025 (Table 8).

Table 8. Parameters of the stream-temperature model (°C, except γ in °C⁻¹).

| Period | α | β | γ | μ | RMSE |
|---|---|---|---|---|---|
| 1996–2005 | 11.8 | 12.4 | 0.21 | 0.6 | 0.52 |
| 2016–2025 | 13.9 | 11.6 | 0.24 | 0.8 | 0.47 |

The upper bound α increased by 2.1 °C, while β decreased, meaning that the river now warms at lower air temperatures than before. Both changes are consistent with the smaller contribution of snowmelt in summer: with less cold water from snow, the stream responds more strongly to air temperature and solar radiation.

### 3.3 Snow water equivalent

Maximum snow water equivalent at Col de Vernay averaged 412 mm in 1986–2005 and 386 mm in 2006–2025, a decrease that is not significant given the large interannual variability. The date of maximum snow water equivalent advanced by 3.6 days per decade, and the length of the melt period shortened by 1.4 days per decade, because melt rates in April and May are higher than in June (Table 9).

Table 9. Trends per decade, 1986–2025 (Theil–Sen; bold: p < 0.05).

| Variable | Trend | Unit |
|---|---|---|
| Melt onset | −5.0 | d |
| Date of max. SWE | −3.6 | d |
| Max. SWE | −7.2 | mm |
| April discharge | +11.4 | % |
| August discharge | −5.8 | % |
| August water temp. | +0.63 | °C |

## 4 DISCUSSION

The advance of snowmelt onset found at Col de Vernay is larger than the average reported for stations below 2 000 m in the western Alps, where the snowpack is thinner and melt starts earlier anyway [2]. At 2 250 m, the snowpack is deep enough to persist into May in most years, so that warmer springs translate directly into earlier melt. The small decrease in maximum snow water equivalent indicates that winter precipitation has partly compensated for the higher winter temperatures at this elevation.

Stream temperature at the intake integrates the effects of air temperature, solar radiation, snowmelt and groundwater inflow along the river. The changes in the parameters of 0 show that the cooling effect of snowmelt in early summer has weakened. Because riparian shading is limited in the upper catchment, further warming could be mitigated only locally, for example by restoring riparian forest along the lower 8 km of the river.

## 5 CONSEQUENCES FOR WATER SUPPLY

The earlier melt shifts the seasonal discharge peak from June to May and lowers flow in August by about 15%. Together with higher temperature, this increases the risk of microbial growth in the distribution network in late summer. The water service of Montvallier plans to raise the share of groundwater in summer and to deepen the intake structure, measures that are part of the city's Montvallier 2040 plan.

Our results also suggest that the temperature of the river at the intake will continue to rise even if air temperature stabilises, as long as the snowpack keeps melting earlier. Monitoring of snow at higher elevations and of groundwater temperature in the alluvial aquifer will be added to the programme in 2027.

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BOOK REVIEW

# A century of ice, water and power

REVIEWED BY NADIA IMESCH
*Alpine Water Research Institute, Montvallier*
Published 30 October 2026 · doi:10.5555/awri.12.3.071

Corinne Mathier: *Glace, eau et énergie. Un siècle d'hydroélectricité et de glaciers dans les Alpes occidentales.* Éditions de la Venoge, Lausanne, 2026. 312 pages, 86 illustrations. ISBN 978-2-9701284-3-6. CHF 48.

Few infrastructures have shaped the Alpine landscape as profoundly as the hydropower schemes built between the 1920s and the 1970s. In her new book, the historian Corinne Mathier follows this development through the lens of the glaciers that feed the reservoirs. The result is an unusual and rewarding combination of engineering history, glaciology and regional politics.

The first part of the book reconstructs how engineers estimated the water available from glaciated catchments before systematic discharge measurements existed. Mathier shows, using the archives of several operators, that early planners assumed glaciers to be stable stores of water; the possibility that they might shrink appears in the files only after the warm summers of the late 1940s. The chapters on the construction of the large arch dams in the 1950s and 1960s, including the Barrage de la Sorne, are vivid and well illustrated with photographs from company archives that have rarely been published.

The second part addresses the present. Mathier interviewed operators, cantonal officials and scientists about the consequences of glacier retreat for hydropower: changing inflow regimes, sediment management, new lakes in deglaciated basins and the debate about raising existing dams. Here the book is at its strongest when it lets the practitioners speak. The chapter on sediment flushing, which draws on the experience at the Lac de Sorne reported in this issue, captures well the tension between operational necessity and ecological concerns.

Readers with a scientific background will occasionally wish for more precision. Figures for glacier volume change are quoted from secondary sources without uncertainties, and the discussion of "peak water" remains qualitative. The maps, although beautifully drawn, lack scales in some cases. These are minor criticisms of a book that is written for a broad audience and succeeds in making a complex subject accessible.

*Glace, eau et énergie* is recommended to anyone interested in the history of Alpine infrastructure and in the choices that the retreat of glaciers imposes on water management. It would also make a good introduction for students entering the field. An English translation is planned for 2027.

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WATER IN MANY LANGUAGES

# Seven voices on glaciers and rivers

Colleagues from the institute's partner organisations were asked to describe, in one or two sentences and in their own language, what glaciers and rivers mean for water in their mountains.

| | |
|---|---|
| **العربية** *Arabic* | الأنهار الجليدية هي خزانات المياه العذبة في جبال الألب، وذوبانها يغيّر جريان الأنهار في الصيف.<br>*Dr. Samira Haddad, Hydrology Department, Beirut* |
| **עברית** *Hebrew* | הקרחונים באלפים הם מאגרי מים מתוקים, והמסתם משנה את זרימת הנהרות בקיץ.<br>*Dr. Noa Ben-David, Institute of Earth Sciences, Jerusalem* |
| **日本語** *Japanese* | 氷河(ひょうが)はアルプスの水(みず)の塔(とう)です。その融解(ゆうかい)は、夏(なつ)の川(かわ)の流れを変えています。<br>*Prof. Kenji Morita, Snow and Ice Laboratory, Sapporo* |
| **中文** *Chinese* | 冰川是阿尔卑斯山的水塔，冰川融化正在改变夏季河流的流量。<br>*Dr. Lin Wei, Cold Regions Research Centre, Lanzhou* |
| **Ελληνικά** *Greek* | Οι παγετώνες είναι οι πύργοι νερού των Άλπεων· η τήξη τους αλλάζει τη ροή των ποταμών το καλοκαίρι.<br>*Dr. Eleni Papadaki, Department of Geology, Thessaloniki* |
| **Русский** *Russian* | Ледники — это водонапорные башни Альп; их таяние меняет летний сток рек.<br>*Dr. Alexei Sokolov, Institute of Geography, Moscow* |
| **हिन्दी** *Hindi* | हिमनद आल्प्स के जल-स्तंभ हैं; उनके पिघलने से गर्मियों में नदियों का प्रवाह बदल जाता है।<br>*Dr. Priya Sharma, Himalayan Glaciology Centre, Dehradun* |

*All sentences express the same idea: glaciers are the water towers of the mountains, and their melting is changing the summer flow of rivers. Japanese readings are given as furigana.*

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## SIX WATER WORDS IN TWELVE LANGUAGES

| | GLACIER | SNOW | ICE | RIVER | LAKE | MELTWATER |
|---|---|---|---|---|---|---|
| **English** | glacier | snow | ice | river | lake | meltwater |
| **Français** | glacier | neige | glace | rivière | lac | eau de fonte |
| **Deutsch** | Gletscher | Schnee | Eis | Fluss | See | Schmelzwas-ser |
| **Italiano** | ghiacciaio | neve | ghiaccio | fiume | lago | acqua di fu-sione |
| **Rumantsch** | glatscher | naiv | glatsch | flum | lai | aua da glatscher |
| **العربية** | نهر جليدي | ثلج | جليد | نهر | بحيرة | مياه الذوبان |
| **עברית** | קרחון | שלג | קרח | נהר | אגם | מי הפשרה |
| **日本語** | 氷河 | 雪 | 氷 | 川 | 湖 | 融雪水 |
| **中文** | 冰川 | 雪 | 冰 | 河流 | 湖泊 | 融水 |
| **Ελληνικά** | παγετώνας | χιόνι | πάγος | ποτάμι | λίμνη | νερό τήξης |
| **Русский** | ледник | снег | лёд | река | озеро | талая вода |
| **हिन्दी** | हिमनद | हिम | बर्फ़ | नदी | झील | पिघला पानी |

*Romansh: Rumantsch Grischun. Arabic and Hebrew are written from right to left; the words are set in right-to-left paragraphs. Hindi uses the Devanagari script, Japanese a mixture of kanji and kana.*

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# INSTITUTE NEWS

## APPOINTMENTS

**Dr. Léa Fournier** has been appointed head of the Glaciology Group from 1 September 2026, succeeding Prof. Hans Zumthurm, who retires after 22 years at the institute. **Dr. Chiara Valsecchi** joins the institute's scientific council as representative of the junior researchers.

## FIELD SEASON 2026

The winter survey on the Glacier de la Sorne took place on 28–30 April with 212 probing points; the autumn survey is planned for 1–3 October, weather permitting. A new automatic weather station on the glacier at 3 050 m was installed in July with the support of Hydro Val-Sorne and will provide the first on-glacier energy-balance data for the massif.

## AWARDS

The AWRI Young Researcher Prize 2026 was awarded to **Ursin Darms** for his work on snowmelt detection from snow-depth records. The prize, endowed with CHF 5 000 by the Fondation Sorne-Rhône, will be presented at the autumn colloquium.

## EVENTS

| Date | Event |
|---|---|
| 5 Nov 2026 | Autumn colloquium, Montvallier |
| 21 Jan 2027 | Workshop: reservoir sediment management |
| 17 Mar 2027 | Public lecture: the future of Alpine glaciers |
| 15 Apr 2027 | Deadline, Vol. 13 No. 1 submissions |

## RECENT THESES

**Ursin Darms (PhD, 2026).** *Snowmelt timing and its hydrological consequences in pre-Alpine and Alpine catchments.* Supervisor: Prof. R. Albrecht.

**Nadine Theytaz (MSc, 2026).** *Debris cover expansion on small glaciers of the Sorne massif from drone surveys.* Supervisor: Dr. L. Fournier.

**Marco Ferretti (MSc, 2025).** *Macroinvertebrate drift during reservoir flushing.* Supervisor: Dr. S. Pfammatter.

## CURRENT PROJECTS

| Project | Topic | Partner | Period |
|---|---|---|---|
| SORNE-ICE | Glacier mass balance and runoff | Hydro Val-Sorne | 2011 – |
| FLUSH-ECO | Ecology of reservoir flushing | Canton, HVS | 2024 –27 |
| SNOWTEMP | Snowmelt and stream temperature | Ville de Montvallier | 2022 –26 |
| DEBRIS-UAV | Debris cover from drone surveys | Université de Montvallier | 2025 –28 |

## PUBLICATIONS BY AWRI STAFF, 2026

Fournier L, Gredig M, Caduff A, Bonvin P (2026) Fifteen years of mass balance on the Glacier de la Sorne. *Bull Alp Water Res Inst* 12(3). doi:10.5555/awri.12.3.041

Darms U (2026) Snowmelt timing and its hydrological consequences in pre-Alpine and Alpine catchments. PhD thesis, Université de Montvallier

Kälin J, Pfammatter S (2026) Drift of benthic invertebrates during turbid flood pulses. *Rev Glaciol Alp* 37:12–29. doi:10.5555/rga.37.012

Valsecchi C, Crettaz M (2026) Warmer streams, earlier snow: implications for drinking-water supply. *J Mt Hydrol Lett* 21:77–88. doi:10.5555/jmhl.21.077

## CALL FOR PAPERS

A special issue on *Water and energy in a changing cryosphere* is planned for 2027. Contributions on hydropower operation, sediment management and ecological flows are particularly welcome. Manuscripts of up to 6 000 words should be submitted through the online system by 15 April 2027.

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