CFD-Based Discharge Curves for Alpine Springs

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***Abstract*—We report on a digitalization solution for alpine spring captures, which allows for continuous, all year-round, monitoring of water discharge and temperature. The solution features an open-hardware data-logger providing the data that fundamentally enables remote data processing. The solution builds on an stage-discharge curve based on Computational Fluid Dynamics (CFD) for the conversion of pressure into flow. Up to three years of data produced by a total of 15 data-loggers have been made publicly available.**

***Index Terms*—Drinking water, alpine springs, CFD, spring capture box, digitalization.**

I. Introduction

Drinking water is a fundamental resource that historically has been given for granted in the Swiss alps. Changing conditions (climate, land use, urban development, etc.) put stress on the availability and quality of drinking water. Rising concerns regarding the correct monitoring of this resource, lead to regulations put in place to foster digitalization and better monitoring. Although surface and groundwater are already monitored in the Swiss and Central Plateau[1], the situation of alpine water springs is not the same. Their monitoring lags behind that of other water sources, e.g. pumped groundwater, and data at the municipality scale is out of the scope of current national programs.

Most captured alpine springs are not directly monitored, and if they are, it is a manual process characterized by sparse and irregular sampling. Moreover, many Swiss alpine springs are located in remote and hard to access locations, making manual uninterrupted monitoring very hard, specially in winter. Current monitoring solutions offered in the market are out-of-budget for small municipalities, and require complicated retrofits neglecting the local situation and needs of the spring capture.

Continuous monitoring of springs leads to a better understanding of their behavior, facilitating true sustainable resource and springshed management. For example, investment decisions (e.g. which type of water turbine to install) are often made without the proper characterization of the spring's behavior. Similarly, decisions on spring revival, decommissioning, and capturing, are also often made with scarce information. Water utilities rely on the GWP (*generelle Wasserversorgungsplanung*) for planning, which defines the facilities needed to guarantee the quality and quantity of the supply of drinking, service, and fire-fighting water, for the present and future settlement area [1]. This instrument also supports decisions concerning the water distribution, and the future infrastructure investments on the basis of spring discharge measurements and its forecast for the following years.

Furthermore, the ecological impact of capturing a spring is often overlooked in spring management. Capturing a spring removes a free running stream from the environment and encloses it into a pipe network. This has an impact in the local ecology, specially on organisms at low trophic levels in

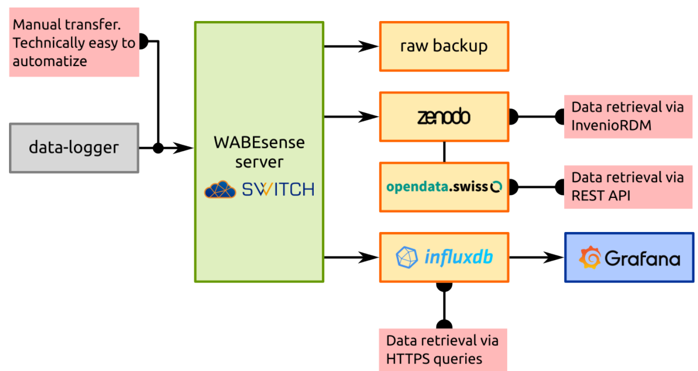

Fig. 1. Overall infrastructure and data flow within the WABEsense system. A data-logger is located at the spring capture. Logged data is retrieved periodically during maintenance inspections. The retrieved data is automatically uploaded to the server raw values are converted into relevant magnitudes using CFD-based discharge curves. Data is made available to the users via Grafana dashboards. Water discharge and temperature data is made publicly available via Zenodo and opendata.swiss. Image licensed under CC-BY-SA by the WABEsense Team.

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[1] https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/naqua-national-groundwater-monitoring.html

the food web. However, little is known about the extent and consequences of this impact.

Springs are a window into the groundwater system, and the science of mountain hydrogeology that studies their behavior is still incipient. Moreover, little is known about the life cycle of springs and how climate change is modifying it. This often results in misconceptions regarding springs and to misaligned policies and regulations. Better understanding of spring behavior and local hydrogeology will lead to improvements in policies and regulations.

Towards a continuous monitoring of alpine springs, we developed the WABEsense system[2]. It provides a solution for bringing more automation and digitalization to water supply facilities, in an energy-efficient manner, ready for use all year round. In addition, the system not only improves the quality of the water production data but also represents the first open-hardware[3] and Free/Libre Open Source Software (FLOSS) solution. The latter addresses the growing concerns about vendor lock-in and increasing switching costs evidenced by water utilities, caused by private companies with outdated business models.

The WABEsense system is placed within a data pipeline that, as an end product, generates the until-now-lacking open data on alpine water production [2]. The open-sourced equipment (hardware and software) is made publicly accessible (see our public repositories for data-logger hardware and firmware[4]) and developed for the future use by municipalities and the research community alike. It is a common good, that saves effort and money, and protects consumer's repair and customization rights[5].

II. WABEsense Solution

WABEsense provides uninterrupted observations of spring discharge and water temperature all year round. It was designed for a common scenario in Swiss alpine springs, in which there is no electricity nor internet connection (no WiFi, GSM, etc.) at the spring capture. The solution complements the current manual measurements with measurements during the interval between two subsequent inspections, enhancing the available data sets.

The WABEsense system comprises several components: a low-power data-logger, a connectivity node, and a server for data processing and publishing. Fig. 1 sketches the flow of data through the components. The data-logger, detailed in Sec. II-A, is located at the spring capture. Firstly, the logged data is retrieved periodically (at least once a year) by an operator (usually the *Brunnenmeister*) during maintenance inspections. Secondly, the retrieved data is brought to the connectivity node (Raspberry Pi wired with internet access) located at the water utility office, where it is automatically uploaded to the

[2]from WABE = "**W**asser **A**llround **Be**hälter", https://www.romag.ch/de/wasser-produkte/brunnenstube-system-wabe/

[3]https://www.oshwa.org/definition/

[4]https://gitlab.ost.ch/sciceg/lippunerag/wabesense

[5]see current debate at the EU Parliament https://repair.eu/news/unlocking-consumer-freedom-eu-parliament-votes-yes-to-right-to-repair/

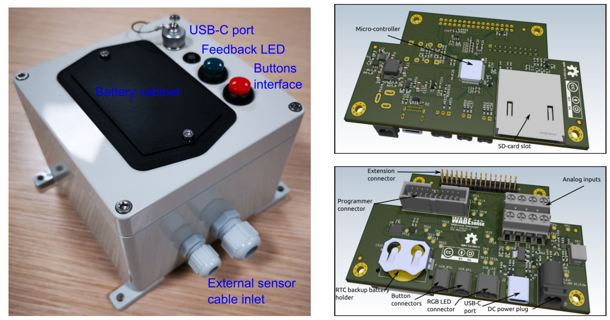

Fig. 2. Data-logger: ready-to-install box and PCB top and bottom views. Images licensed under CC-BY-SA by the WABEsense Team.

server. The server is a Switch Engine[6] running Linux Ubuntu, and its role is to process the data and make it available to the users via Grafana dashboards[7]. The measured pressure is converted to spring water discharge, using the CFD-based discharge curve described in Sec. II-B. Finally, water discharge and temperature data is made publicly available via Zenodo repositories [2], and listed at the opendata.swiss directory.

A. Data-logger

To gather data in spring captures of alpine springs, an energy-efficient data-logger unit has been designed that forms a handy, easy to install piece of measurement equipment at low cost. The data-logger unit is directly attached at the spring capture box and does not require any further infrastructure on site—in particular, operation is guaranteed in absence of any existing power supply or mobile network coverage.

Fig. 2 shows the housing box and electronics of the developed data-logger unit. The printed circuit board (PCB) hosts an ultra-low-power Arm Cortex M4 micro-controller (e.g. STM32L496RGT6), which largely remains in standby mode except for a short periodic measurement sequence (with typical duration of $250\,\mathrm{ms}$, triggered every $10\,\mathrm{min}$). The device can also be activated via user buttons by an operator for reading out logged data points onto a USB memory stick, or via USB cable when connected to a PC or laptop for configuration purposes.

The data-logger is powered by three Lithium battery cells ($3.6\,\mathrm{V}$, $2600\,\mathrm{mAh}$) and backed up by a $3\,\mathrm{V}$ RTC CR2032 battery (which ensures a continuous time base when the main batteries get swapped during maintenance). The power budget allows for uninterrupted data logging operation over at least one year. Besides $3.3\,\mathrm{V}$ system-level supply, the logger provides the necessary $5\,\mathrm{V}$ for the USB interface and $17\,\mathrm{V}$ for up to two external sensors.

The external sensor in use is a combined pressure/temperature transmitter (0 to $100\,\mathrm{mbar}$, -40 to $50\,\mathrm{°C}$), which provides spring water pressure and temperature data to the data-logger system. Additional internal system monitoring is realized through a BME280 sensor, which in combination with the logged battery voltage, gives insight into the system state.

[6]https://www.switch.ch/en/switch-engines

[7]https://grafana.com/oss/grafana

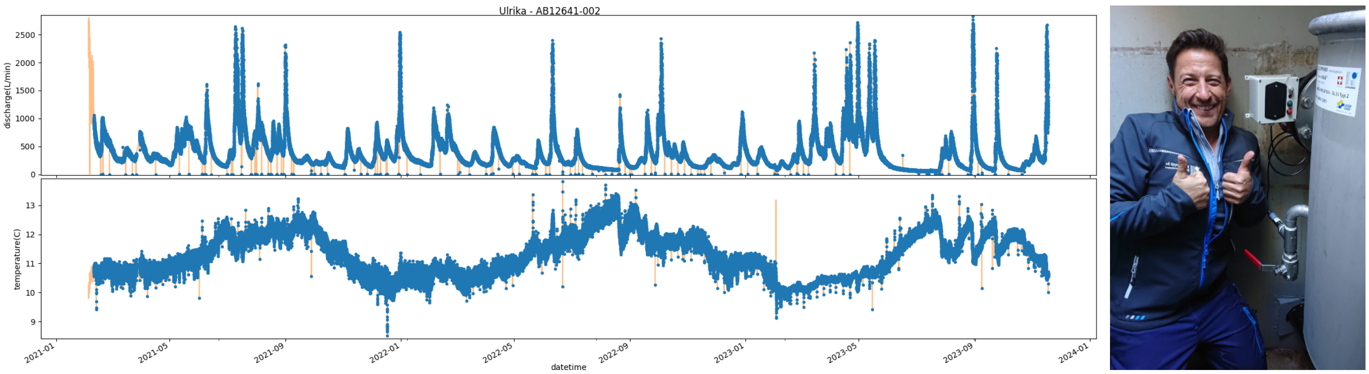

Fig. 3. Collected and published data from spring Ulrika, Oberriet SG (left). The continuous line depicts all the collected that, part of it is removed from the published results. Blue dots correspond to the published data [2]. One of the data loggers successfully installed by Uli Lippuner AG for field testing in a spring capture box at Schiers GR (right).

Similar to the open hardware that fosters reuse and modification beyond the presented project, the open firmware is designed for flexibility and to ease system expansion. It features rich human machine interfaces like buttons to control system and data operation, LEDs for visual status feedback, interfaces for firmware updates and data export, optionally involving PCB flash memory, USB memory stick or SD card.

The data storage of $4\,\mathrm{MB}$ flash memory can store over 130’000 time-stamped data points (water pressure and temperature; ambient temperature, pressure and humidity; battery voltage), corresponding to over two years of data at $10\,\mathrm{min}$ sampling period. In addition, system configuration and activity history of logged system events are retained. The wealth of logged data allows for subsequent data analysis and processing, as further detailed in Sec. II-B.

Since its first release, there have been 25 data-loggers deployed. The first five were used for the initial testing of the prototype and the identification of unforeseen requirements. This was followed by the deployment of five modified prototypes, and then 15 latest version data-loggers. These 15 loggers are located at following municipalities: Bonaduz GR (4), Bregaglia GR (2), Hergiswil NW (2), Oberriet SG (1), Schiers GR (2), Zernez GR (1), Susch GR (2), Zug ZG (1). The largest uninterrupted interval of logged data spans three years (including logger maintenance) of the spring Ulrika at Oberriet SG and is displayed in Fig. 3.

B. CFD-based Discharge Curves

The WABEsense solution provides an indirect measurement of the spring water discharge which flows through the spring capture box. In its current version, a pressure must be converted into a flow. Classically, this conversion is done via a stage-discharge relationship, or discharge curve for short. This curve links the amount of water flowing though the spring capture box, Q, and the corresponding measured pressure, p (see Fig. 5).

The shape of the discharge curve depends on the geometry of the spring capture box. Since the geometry of the capture box can change from site to site, no single curve can fit all possible boxes. Also, the geometries encountered during the project could not be easily and objectively linked to tabulated discharge curves. Therefore, a 3D CFD simulation [3] is run for each geometry at different values of discharge. Fig. 4 shows a snapshot of the results of these simulations. The results provide simulated pressure measurements for different discharges. To generate the discharge curve from these results, we followed the approaches discussed in [4, 5], and fitted a model of the form

$$Q(\eta, \boldsymbol{\lambda}) = k(\eta, \boldsymbol{\lambda}) Q_*(\eta) \tag{1}$$

where η is the spring capture box outlet fill-ratio, $\boldsymbol{\lambda}$ stands for all geometrical parameters of the spring capture box, and Q_* is the dimensionless discharge reported in [5]. The fill-ratio dependent discharge coefficient k is adjusted to fit the simulated data. Fig. 5 shows the results obtained for the spring capture box at Paliu Fravi (Bonaduz GR). It depicts the simulated data, the fitted curve, and manual reference measurements taken on the field; it also includes some stage indicators of the capture box (nominal flow, flow at full outlet, flow at full box). Note that these reference measurements were not used to fit the discharge curve.

III. Discussion and Conclusion

Herein we have presented the WABEsense data-logger as a solution for the continuous monitoring of alpine springs in remote locations. The logged raw pressure data is transformed into the relevant water discharge via a customized discharge curve, based on CFD simulations. The data-loggers and the data processing pipeline have been tested for the last three years, leading to progressive improvements of the workflows. This has allowed us to identify enhancements that will simplify data retrieval and increase acceptability of the solution, such as contactless data readout from the data-logger (e.g. via Bluetooth).

The solution complements the current manual measurements done by operators with measurements between two inspection visits. In this way, it improves the observability of the springs, facilitates the research of their behavior, and

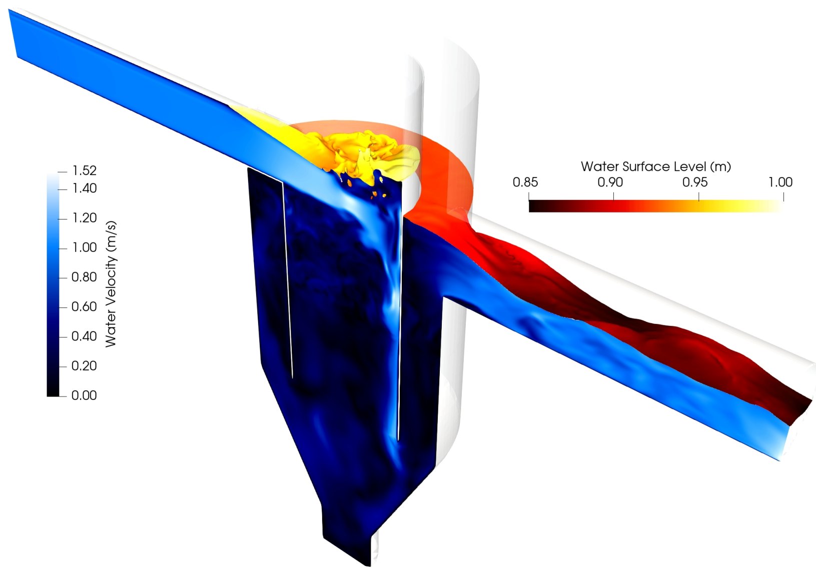

Fig. 4. CFD simulation snapshot for a specific spring capture box geometry. Image licensed under CC-BY-SA by Alex Weber.

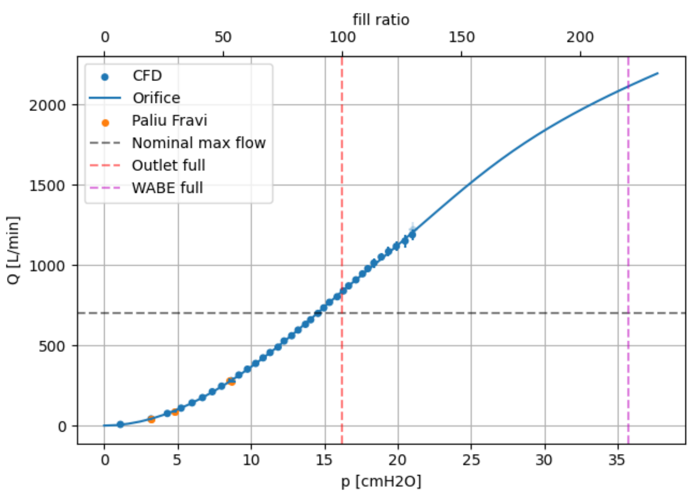

Fig. 5. Discharge curve for spring capture box at Paliu Fravi, Bonaduz GR. The plots shows manually measured data and the results of CFD simulations in orange and blue circles, resp. The continuous line is the model used to fit the CFD results. Dashed lines show several stage indicators of the capture box: nominal flow, flow at full outlet, flow at full box.

improves decision-making based on abundant water production data. This data can be also used to inform policy-makers to obtain better regulations.

The open nature of the solution also allows us to transparently adapt it to other capture boxes different from the WABE. This will enable us to monitor springs that have been captured many decades ago, without large retrofitting investments. The flexibility designed into the logger should also allow us to apply it to very different contexts than the one described here.

Finally, the availability of open discharge data will promote more research into the hydrogeology and ecology of alpine springs, as well as support the development of state-of-the-art data analytics for water utilities (better GWP, detailed forecasts, etc.).

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References

[1] S. Mürner, “Richtfahrplan GWP - Papiertiger oder nützliches Führungsinstrument?” in *Wasser 2018, 21st Lippuner Seminar*, 2018.

[2] J. P. Carbajal, R. Housseini, J. Lippuner, and D. Lippuner. (2023, Dec.) Discharge of springs monitored during the WABEsense project. [Online]. Available: https://zenodo.org/doi/10.5281/zenodo.8239367

[3] C. Greenshields, *OpenFOAM v11 User Guide*. London, UK: The OpenFOAM Foundation, 2023.

[4] G. Isenmann, S. Bellahcen, J. Vazquez, M. Dufresne, C. Joannis, and R. Mose, “Stage–discharge relationship for a pipe overflow structure in both free and submerged flow,” *Engineering Applications of Computational Fluid Mechanics*, vol. 10, no. 1, pp. 283–295, Jan. 2016.

[5] A. R. Vatankhah and M. Bijankhan, “Discussion of “New Method for Modeling Thin-Walled Orifice Flow under Partially Submerged Conditions” by David Brandes and William T. Barlow,” *J. Irrig. Drain Eng.*, vol. 139, no. 9, pp. 789–793, Sep. 2013.