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HP-CatCH: linking hydropower infrastructure to their hydrological catchments in Switzerland

Yann Yasser Haddad[1], Elena Raycheva[2,3], Jonas Savelsberg[3], Petra Sieber[1], Lukas Gudmundsson[1], and Sonia I. Seneviratne[1]

[1]Institute for Atmospheric and Climate Science, ETH Zürich, Zürich, Switzerland
[2]Power Systems Laboratory, ETH Zürich, Zürich, Switzerland
[3]Energy Science Centre, ETH Zürich, Zürich, Switzerland

Correspondence: Yann Yasser Haddad (yasser.haddad@env.ethz.ch)

Abstract. Detailed hydropower modeling in mountainous regions such as Switzerland is essential to optimize resource planning and inform the energy transition. To foster this process, we introduce HP-CatCH, an open-access dataset that maps topological configurations of hydropower cascades in Switzerland and links hydropower infrastructure to the associated hydrological catchments. In total, the components and topology of 48 cascades are defined, including 106 reservoirs and covering 95% and 93% of Swiss hydropower storage and pumped-storage capacity, respectively. Additionally, 601 run-of-river hydropower plants are modeled. The potential of the dataset is demonstrated by reconstructing historical inflows into reservoirs and run-of-river hydropower plants using simulated runoff from the hydrological model PREVAH. The resulting inflows exhibit large spatiotemporal variability, highlighting the relevance of such detailed and spatially explicit hydropower representation for energy system modeling and hydroclimatic impacts studies.

1 Introduction

Hydropower remains the largest source of renewable electricity worldwide and is a key component of the energy transition (IHA, 2025). This technology is particularly important in water-rich countries like Switzerland, where it constitutes around 60% of domestic electricity generation (SFOE, 2025). Switzerland's hydropower capacity is of relevance not only nationally, but also regionally. The country lies at the center of large inter-country electricity exchanges and helps balance out the regional grid (Swissgrid AG, 2026). The Swiss hydropower landscape consists of three main power plant types: run-of-river, storage and pumped-storage. Run-of-river (RoR) plants are typically deployed along the river network and have minimal or no water storage capacity, relying directly on river discharge. In contrast, storage and pumped-storage plants use reservoirs to manage water more flexibly. These reservoirs collect water either naturally from their catchment areas or via pressure tunnels that divert water from nearby areas. Although storage plants are fewer in number in Switzerland, they are usually larger in capacity and contribute nearly half of national hydropower generation. Pumped-storage facilities, on the other hand, serve primarily as electricity storage systems, transferring water between reservoirs to store and release energy as needed. Hydropower infrastructure can also operate in cascading systems, called "hydropower cascades", where a series of reservoirs and hydropower plants are hydraulically connected, enabling water to be reused downstream or upstream for energy storage or generation.

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Hydropower is highly dependent on water availability, making it prone to climate change and variability (IHA, 2019; IRENA, 2023). Recent droughts and heatwaves have already led to a decline in hydropower generation across the globe (van Vliet et al., 2016; Ember, 2023). More locally, a growing body of literature showcases context-dependent climate effects on hydropower in Switzerland (Savelsberg et al., 2018; Wechsler and Stähli, 2019; Wechsler et al., 2023; Haddad et al., 2025; Hänggi and Weingartner, 2012; Schaefli et al., 2019; SCCER-JASM, 2020). For instance, hydropower generation varies considerably depending on geographic location and topography, with power plants located in snow and glacier-dominated catchments responding differently to climate change and variability compared to rainfall-dominated regions.

A sound technical representation of hydropower is therefore essential to accurately assess hydro-climatic effects on past and future generation and to enable a climate-resilient energy transition. This entails identifying infrastructure locations and their contributing catchments, specifically by mapping water intake points, where water is abstracted and diverted, and pressure tunnels that facilitate water transport between system components. While previous initiatives have documented the locations and technical specifications of hydropower plants and reservoirs at both the Swiss (SFOE, 2022, 2023) and international scale (JRC, 2019; Global Energy Monitor, 2025), they do not provide the topological link between those plants and their hydrological catchments. A more specialized effort collected spatial and technical information for more than 300 power plants in Switzerland, allowing them to be connected to their respective hydrological catchments and water intake points (Balmer, 2012). However, besides publicly accessible data, this work includes proprietary information hindering a free distribution. Moreover, this data product does not capture the relationship between different elements of the Swiss hydropower infrastructure. Another endeavor mapped more than 600 run-of-river power plants in Switzerland to their corresponding water intake points and catchment areas, but did not include storage hydropower (Haddad et al., 2025). A more recent study delivered an exhaustive account of large hydropower systems in the Italian Alpine Region, including the interconnections between different nodes within the system (Galletti et al., 2025). This work offers a valuable blueprint for developing a comprehensive description of hydropower systems topologies.

Recent research further highlights the added-value of such detailed granular modeling for climate and energy policy. A study on the Lower Mekong Basin analyzed the impacts of river flow extremes on energy transition pathways in the region (Xie et al., 2025). Additionally, a spatially explicit representation of hydropower cascades demonstrated that adaptive hydropower reservoir operation in South Western China's energy system can reduce the costs of the energy transition as well as water consumption (Liu and He, 2023). Together, these studies underscore that explicit hydropower modeling is not only a technical exercise, but also an important component for robust energy planning in hydropower-dependent regions.

The aim of this study is to improve the representation of hydropower cascades in Switzerland and the link between hydropower infrastructure and their associated hydrological catchments. We introduce a new dataset, HP-CatCH, that addresses those two gaps. It provides information on the components and topology of reservoirs for 48 hydropower cascades, representing 95% and 93% of total Swiss hydropower storage capacity and pumping capacity, respectively. Additionally, it connects 601 run-of-river power plants to their respective hydrological basins. The dataset relies solely on publicly accessible data sources to ensure transparency, reproducibility and reusability. Based on the reconstructed topologies and the links to the hydrological catchments, inflows into reservoirs and run-of-river hydropower plants are derived. HP-CatCH's approach extends previously

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published frameworks and is transferable to similar hydropower-rich regions with complex cascade systems. This paper is structured as follows: first, we present the underlying datasets used to produce HP-CatCH and outline the methodology for deriving reservoir inflows based on these topologies; second, we describe the resulting cascade components and reservoirs topology; third, we display the usefulness of the HP-CatCH dataset by deriving the inflows into the considered hydropower infrastructure. Finally, we summarize the contributions and limitations of this work and offer perspectives for future research.

2 Input data and methods

2.1 Hydropower infrastructure

HP-CatCH relies on several open-access datasets. The technical and spatial specifications of hydropower plants with capacities of 300 kW or more are obtained from the Hydropower Statistics (WASTA) database (SFOE, 2022). They are classified into four categories: run-of-river (L), storage (S), closed pumped-storage and open pumped-storage (both designated by P here). To identify reservoirs, pressure tunnels and water intake points, we employ SwissTLM3D, the topographic model of Switzerland (swisstopo, 2023). These elements help establish the hydraulic connectivity between reservoirs, defined here as *cascade topology*. Additionally, the Swiss residual water map is used to verify and add water intake point data (FOEN, 2007). The list of the hydropower system components is complemented by technical documentation published by hydropower operators, when available. Furthermore, *topological aggregation* is applied to some complex hydraulic schemes, such as the Oberhasli, where certain reservoirs were either omitted or combined. Each component in the system is then assigned to its corresponding hydrological sub-basin, using pre-defined 2 km^2 topographical sub-basin areas for Switzerland provided by the Swiss Federal Office of Environment (FOEN, 2010). Delineated based on topography, these polygons are connected through a hierarchical structure that facilitates the definition of upstream drainage areas. By leveraging the nested nature of these sub-basins, we infer the upstream catchment area of each component, which is essential for deriving reservoir inflow estimates.

2.2 Simulated runoff

Estimating inflows into the hydropower infrastructure requires high-resolution runoff or streamflow data. This study relies on observation-driven hydrological simulations from the PREVAH model, which provide grid-cell runoff for hydrological Switzerland (i.e., the union of political Switzerland and all areas draining into it) (Viviroli et al., 2009a, b). PREVAH is considered a reference in hydrological modeling in Switzerland and has been employed in many climate impact studies (FOEN, 2021; Brunner et al., 2019; Horton et al., 2022). Here gridded runoff output (in mm d^{-1}) at a daily temporal resolution and a spatial resolution of 500 meters is used. The data is converted into m^3 s^{-1} and aggregated to the sub-basin level, at a 2 km^2 resolution, to ensure consistency with the employed topographic modeling. It is important to note that PREVAH primarily simulates responses to natural hydrological processes, with limited representation of anthropogenic regulation.

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2.3 Derivation of inflows into hydropower infrastructure

The estimation of inflows into hydropower plants and reservoirs depends on the hydrological sub-basins contributing to each of them. By integrating information on the water intake points, the natural catchment areas defined by the location of the hydropower infrastructure, as well as the reservoir hierarchy, we reconstruct the catchment area of each system component.

2.3.1 Identification of contributing sub-basins

We define the following framework for determining catchment contributions to reservoirs. Let r be a reservoir, $R_u(r)$ be the set of upstream reservoirs of r and $W(r)$ be the set of water intake points associated with r. Two approaches can be considered to account for $R_u(r)$ in the assessment of contributing catchments, as illustrated in 1.

The "*direct contributors*" approach adopts a conservative strategy by considering only the catchments $C_d(r)$ that drain directly into r or its water intake points $W(r)$, thus omitting those that contribute to any reservoir in $R_u(r)$. This assumes that upstream reservoirs $R_u(r)$ fully retain the water draining into them, thus not reaching r. This approach enables the decoupling of water inflows induced by human intervention from natural inflows.

In contrast, the "*all contributors*" approach considers all the catchments $C_a(r)$ that contribute to both r and its upstream reservoirs $R_u(r)$, such that $C_d(R_u(r)) = \bigcup_{r_u \in R_u(r)} C_d(r_u)$ and $C_a(r) = C_d(r) \cup C_d(R_u(r))$. This assumes that all the water that contributes $R_u(r)$ eventually contributes to r as well, providing a hydraulic continuity.

These two approaches can be used to different ends. Aggregating values based on the "*all contributors*" methodology over long time frames, such as yearly scale, would allow for a good understanding of the total water volumes flowing into a reservoir, as most inflows tend to be turbined downstream over the course of a year. Moreover, the "*direct contributors*" methodology is useful for energy systems modeling, as the energy system decides when to release water from a reservoir to another, therefore requiring only natural inflows as input to the system.

For the run-of-river power plants, we apply an approach similar to the "*all contributors*" deployed for the reservoirs. Let h be a run-of-river hydropower plant and $W(h)$ be the set of water intake points associated with h. We consider the entire upstream area of the plant's location and all sub-basins contributing to $W(h)$, regardless of the presence of upstream reservoirs.

Once the set of contributing catchments C is identified, inflows into the hydropower reservoir r or hydropower plant h at time t are estimated by summing the discharge values $q_i(t)$ across all relevant catchments $i \in C$, resulting in a discharge value $Q_r(t) = \sum_{i \in C} q_i(t)$ and $Q_h(t) = \sum_{i \in C} q_i(t)$.

3 Description of the dataset

In the HP-CatCH dataset, hydropower cascades are represented in a tabular format, indicating composition and relationship between reservoirs. The components of the hydropower cascades are described with the following attributes:

– **CascadeID:** A unique identifier for the cascade.

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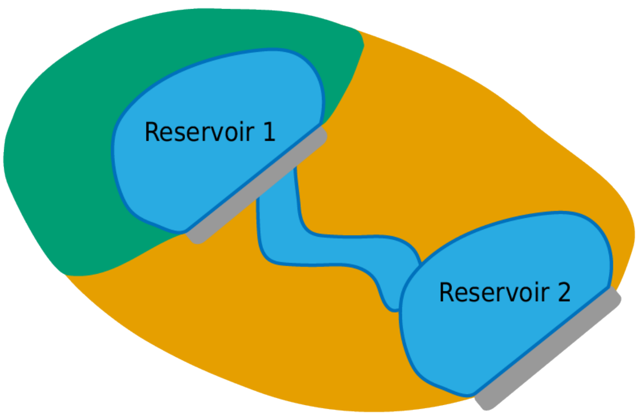

Figure 1. Illustration of the direct and all contributors approaches to identifying contributing catchment area to reservoir inflows.

- **NodeID:** A unique identifier for the component. The leading digit indicates the component type: 1 for reservoirs, 2 and 4 for water intake points, 3 for pressure tunnels and 5 for hydropower plants. For example, the NodeID 50101 corresponds to the Sarelli power plant.
- **NodeName:** The name of the component (omitted for pressure tunnels).
- **NodeType:** The functional type of the component: Reservoir, Water Intake Point, Hydropower Plant (S), Hydropower Plant (P), Hydropower Plant (L) and Pressure Tunnel.
- **WASTA:** The corresponding identifier of the hydropower plant from the WASTA database. It is only available if NodeType is a hydropower plant.
- **EZGNR:** The 2 km^2 Swiss hydrological sub-basin ID corresponding to the node. This is only available for Water Intake Points and Reservoirs.
- **Druckstollen:** The pressure tunnel identifier, stemming from the SwissTLM3D or the residual flows datasets.
- **LAKE_GWL_NR:** The SwissTLM3D identifier of the lake corresponding to a reservoir.

In addition to the components of a cascade, the reservoir topology is defined. These relationships are described in a database with the following attributes:

- **CascadeID:** Number identifying the cascade.
- **FlowsFromID:** NodeID of the upper reservoir from which the water is discharged.

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– **FlowsIntoID:** NodeID of the lower reservoir into which the water is discharged.

– **Level:** Number representing the hierarchical position of the reservoir within the cascade. Lower numbers indicate more downstream reservoirs, and higher numbers more upstream.

An example of the dataset for the Kraftwerke Sarganserland cascade (ID 87) is provided in Tables 1 and 2, and visualized in Fig. 2.

Table 1. Table of components for the Kraftwerke Sarganserland cascade. X represent values that are not available for the NodeType.

CascadeID	NodeID	NodeName	NodeType	WASTA	EZGNR	Druckstollen	Lake_GWL_NR
87	40108	Gafarrabach	Water Intake Point	X	191604	SG-073	X
87	40109	Siezbach	Water Intake Point	X	122186	SG-075	X
87	40110	Scheubsbach	Water Intake Point	X	162227	SG-076	X
87	40111	Mattbach	Water Intake Point	X	190319	SG-077	X
87	40112	Gufelbach	Water Intake Point	X	118407	SG-078	X
87	40113	X	Water Intake Point	X	196250	SG-079	X
87	40114	Seez	Water Intake Point	X	128740	SG-080	X
87	10094	Gigerwaldsee	Reservoir	X	166675	X	CH0093670000
87	30103	X	Pressure Tunnel	X	X	SG-083	X
87	50100	Mapragg	Hydropower (P)	104600	X	X	X
87	10095	Mapraggsee	Reservoir	X	137266	X	CH0093660000
87	30104	X	Pressure Tunnel	X	X	SG-081	X
87	50101	Sarelli	Hydropower (S)	104700	X	X	X

The link between reservoirs and their hydrological catchments is embedded in the cascades tables, whereas this step is managed in a separate table for run-of-river power plants. They are identified directly by the WASTA number and the identifiers of the corresponding sub-basins are given in the EZGNR column. An excerpt of the dataset is provided in Table 3.

The information gathered in those different datasets is visualized in Fig. 3. Panels (a), (b) and (c) pertain to cascades and reservoirs, whereas panels (d) and (e) to run-of-river power plants. Panel (a) shows the spatial distribution of the different cascades and their components. Panel (b) depicts the catchment area for reservoirs using the "*direct contributors*" approach and (c) the difference in catchment area between the "*all contributors*" and "*direct contributors*". Under the "all contributors" approach, the drainage areas of approximately half of the reservoirs increase compared to the "direct contributors" approach, as it only affects more downstream reservoirs. The magnitude of this increase varies between cascades, ranging from around 4 to 2061 km^2, depending on the complexity and the size of the upstream system.

Panel (e) shows the catchment area for run-of-river power plants, revealing large geographical disparities. RoR power plants tend to have larger drainage areas than reservoirs, as they are located along major Swiss rivers, such as the Rhine and the Aare.

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Table 2. Reservoir topology for the Kraftwerke Sarganserland cascade. For the uppermost and lowermost nodes, respectively *FlowsFromID* and *FlowsIntoID* are represented by an X.

CascadeID	FlowsFromID	FlowsIntoID	Level
87	40108	10094	3
87	40109	10094	3
87	40110	10094	3
87	40111	10094	3
87	40112	10094	3
87	40113	10094	3
87	40114	10094	3
87	10094	10095	2
87	10095	X	1

Table 3. Excerpt of the dataset linking run-of-river power plants to their hydrological sub-basins

WASTA	EZGNR
100550	171590
100575	137240
100600	161376, 176170
100625	185410
100700	144231, 137240, 195632

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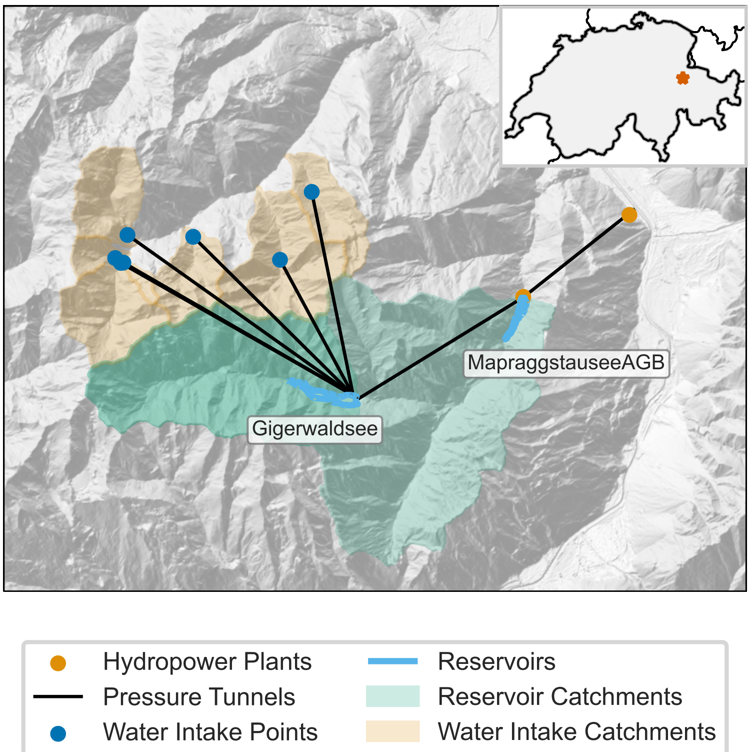

Figure 2. Overview of the Kraftwerke Sarganserland cascade showing the spatial configuration of its components and the location of the cascade in Switzerland.

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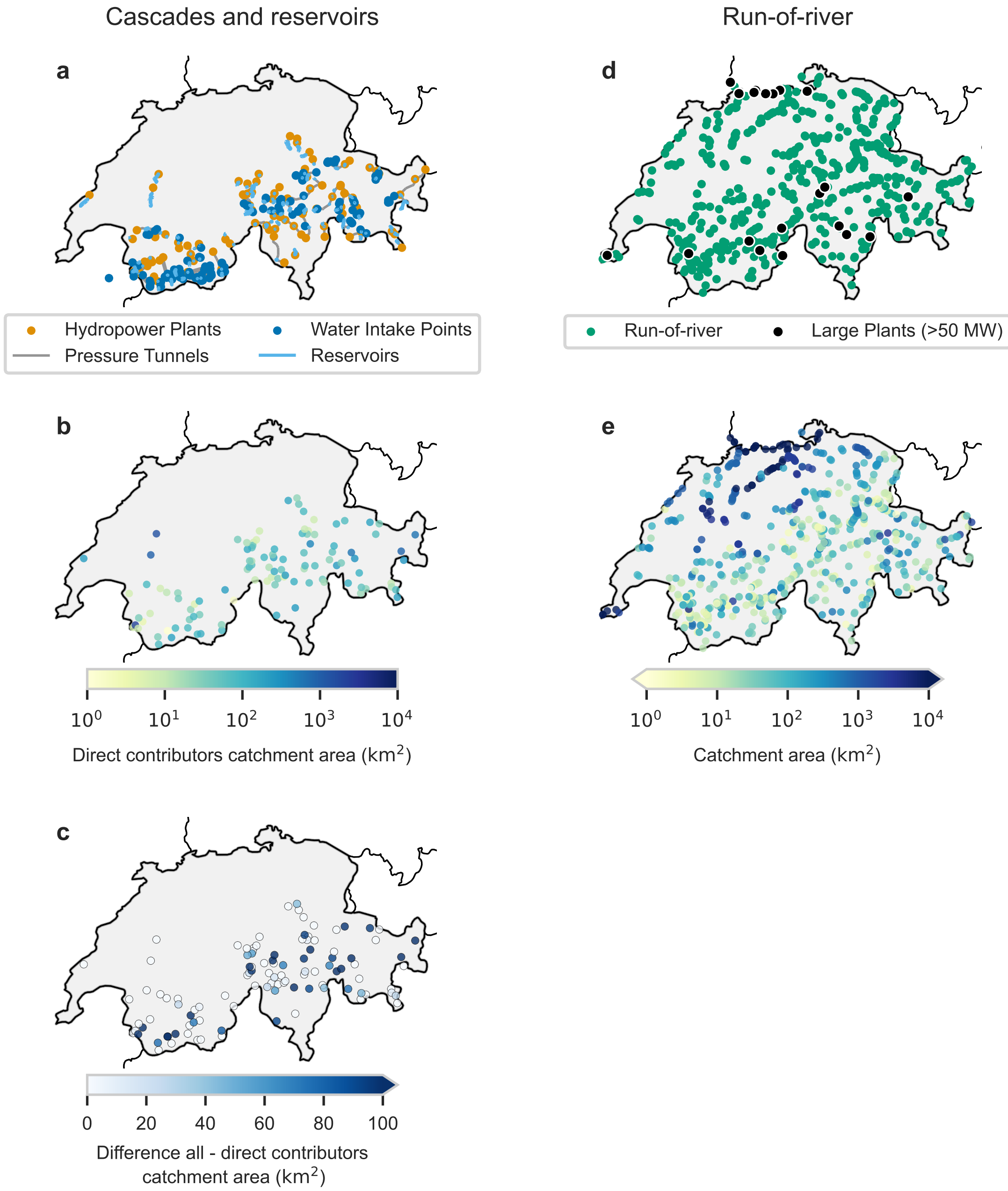

Figure 3. Maps of the HP-CatCH database and its components. Panels (a), (b) and (c) correspond to the hydropower cascades database: (a) shows the spatial distribution of the cascades components, (b) depicts the catchment area of reservoir following the "*direct contributors*" approach and (c) highlights the differences in the catchment areas between the "*all contributors*" and the "*direct contributors*". Panels (d) and (e) correspond to the run-of-river database: (d) illustrates the spatial distribution of the run-of-river power plants and (e) the catchment area of those facilities.

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4 Inflows into hydropower infrastructure

The dataset presented in this study can serve multiple purposes, one of which is to determine the inflows feeding into reservoirs or run-of-river power plants. Leveraging observations-driven hydrological simulations of Switzerland, we reconstruct the past inflows into hydropower infrastructure, from 1991 to 2022. This detailed estimation enables the exploration of weather and climate impacts on these inflows.

4.1 Inflows into reservoirs

Inflows are derived for each reservoir based on the cascade topologies, with results shown in Fig. 4. The mean monthly inflow into all reservoirs combined doubles in almost all months when accounting for the entire upstream contributing area rather than solely the immediate sub-basins (Fig. 4a). Moreover, 5th-95th percentile ranges indicate a large spread due to hydroclimatic variability across years, which is most pronounced in the summer half-year.

In (b), the inflows based on the "*all contributors*" approach are spatially disentangled. The results can be closely related to Fig. 3b, as reservoirs with larger inflows tend to have larger catchment areas. In addition, the geographical disparities can also be explained by varying hydrological regimes. For example, snow-dominated and glaciated catchments contribute to large inflows into reservoirs, although they may have a smaller catchment area.

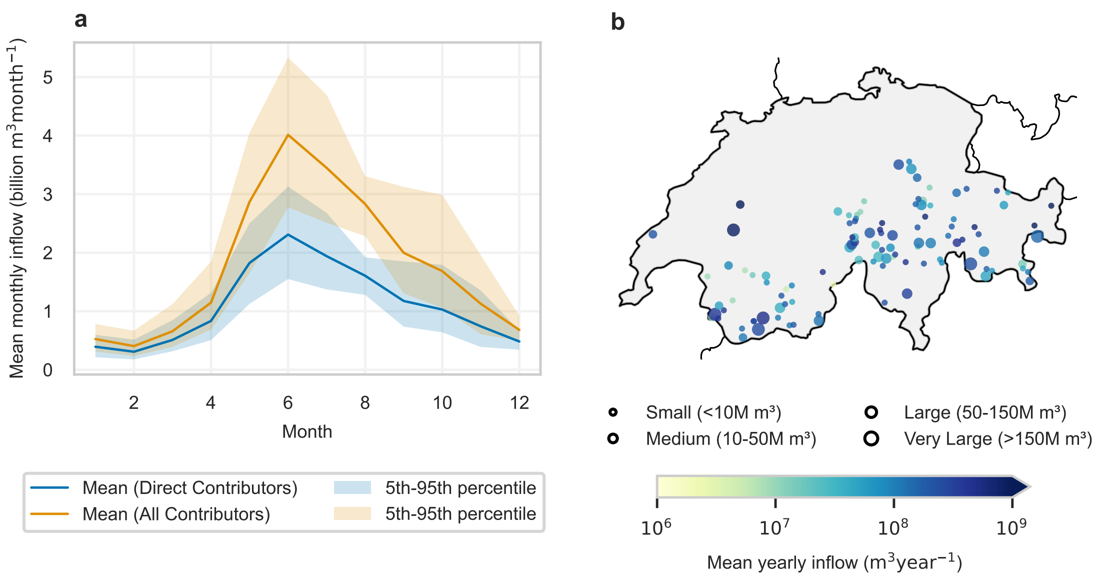

Figure 4. Temporal and spatial representation of inflows into reservoirs. (a) depicts the mean monthly inflow into all reservoirs combined, both for the "*all*" and "*direct*" contributors approach, along with their respective year-to-year spread indicated with the 5th-95th percentile range. (b) shows a map of the mean yearly inflow into each reservoir, assuming a "*all contributors*" approach, with a dot size varying depending on the reservoir capacity.

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4.2 Inflows into run-of-river power plants

Similar to the analysis for reservoirs, discharge data is combined with information on the contributing sub-basins to derive inflows at each run-of-river power plant (Fig. 5). The magnitude of mean monthly inflow into RoR hydropower significantly exceeds that of reservoirs. Additionally, the spread is large throughout the year, reaching around 80 billion m^3 for certain months.

As illustrated in (b), this is mainly due to the larger number of power plants and their location along rivers with greater cumulative discharge. Consistent with the findings in the previous section, the spatial patterns mirror those found in Fig. 3 (e), where power plants with large catchment areas tend to have the larger mean yearly inflows.

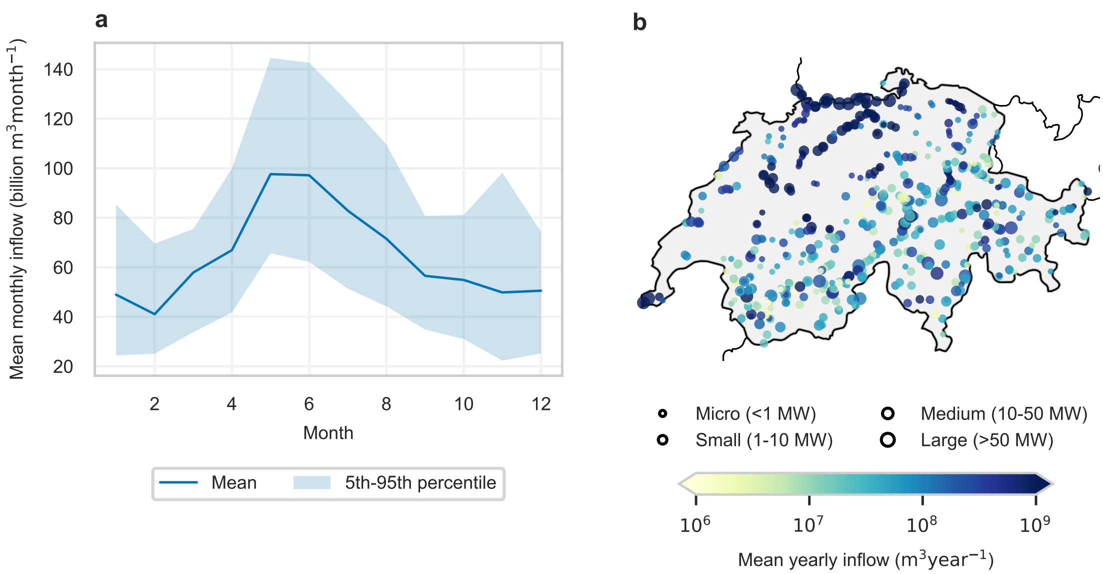

Figure 5. Temporal and spatial representation of inflows into run-of-river power plants. (a) depicts the mean monthly inflow into all run-of-river power plants combined. (b) shows a map of the mean yearly inflow into each plant, with a dot size varying depending on the plant's capacity.

5 Discussion and conclusions

This study provides a comprehensive representation of major Swiss hydropower cascades, run-of-river power plants and their associated hydrological catchments by connecting several publicly available datasets. It highlights the potential of open-access data and their downstream applications. This endeavor enables, for example, the subsequent derivation of inflows into the defined infrastructure and an improved understanding of the impacts of hydroclimatic change and variability on these resources. While previous studies already leveraged existing representations of Swiss reservoirs and power plants (Balmer, 2012; Savels-

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berg et al., 2018), this work expands on previous literature and provides open-access representations for a comprehensive set of hydropower cascades and run-of-river power plants.

The development of this dataset requires certain structural simplifications. Notably, the prescribed topological connections handle only upstream to downstream connections to facilitate the estimation of natural inflows into reservoirs. However, the bidirectional connections of pumped-storage schemes can be deduced from the data product, and subsequently implemented in energy systems models. Moreover, we address instances where pressure tunnels bypass reservoirs to directly feed downstream power plants. To ensure that this water is considered, we assign this diverted flow to the closest upstream reservoir.

The structure of the dataset aims to reduce data redundancy while ensuring dataset interoperability through shared key attributes. Indeed, this work does not cover infrastructure characteristics, unlike other similar datasets (Balmer, 2012; Galletti et al., 2025). As the underlying datasets used in this study, such as the WASTA database, already contain several technical descriptors, the framework introduced here mainly serves to bridge the gap in the hydrological connection between hydropower infrastructure and their contributing catchments.

Beyond the dataset design choices, the resulting inflow derivations face inherent challenges in their validation, due to the lack of available open data on inflows into reservoirs and power plants. Moreover, those inflows are computed based on discharge aggregated on 2km ^{2} polygons, sometimes leading to aggregating over multiple creeks and river branches whereas only one is abstracted from and redirected to hydropower infrastructure. A previous paper derived inflows into reservoirs for energy systems modeling, and reported values around 1.5 to 3 times higher than the ones shown in Fig. 4 (Savelsberg et al., 2018). Due to the differing underlying data and assumptions, benchmarking remains difficult. However, this discrepancy highlights the need for open-access validation data to further improve hydropower modeling.

Nonetheless, this dataset provides a transparent framework for modeling Swiss hydropower cascades, run-of-river power plants and their respective inflows. It serves as a solid foundation for a more realistic representation of complex hydropower systems in energy systems modeling and climate impacts analyses and can serve as an additional blueprint for other hydropower-heavy countries. By providing those representations, historical and future inflows into hydropower infrastructure can be computed and subsequently integrated in an energy system model. The importance of this extends beyond national energy planning, as climate impacts on hydropower might affect cross-border country exchanges and regional balancing of the grid. This opens new avenues for including better weather and climate information in energy system modeling, an aspect that is largely unsystematic in current modeling efforts.

6 Code and data availability

The code used in this study is available on GitHub at https://github.com/yasserhaddad/HP-CatCH, under MIT license. The HP-CatCH database, together with the required files to run the code, are openly accessible at https://doi.org/10.3929/ethz-c-000800479, under the Creative Commons Attribution 4.0 International license (Haddad et al., 2026). The data include the cascades nodes and topology as well as the run-of-river catchments, provided in CSV (.csv) files. Additionally, the data is provided in four shapefiles (.shp), namely reservoirs, water intake points, pressure tunnels, hydropower plants, combining the cascades

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and run-of-river data as well as capacities extracted from the WASTA database. All shapefiles employ the CH1903+/LV95 coordinate reference system (EPSG:2056). The reconstructed inflow time series are provided as two Zarr (.zarr) datasets. To support reproducibility of the processing pipeline, the archive additionally includes the input datasets used to derive HP-CatCH: the WASTA 2023 hydropower plant registry (.csv), the sub-basin polygons (.gpkg), residual flow map (.csv), and reservoir volume and capacity data (.csv, with an accompanying name-matching table). This version of HP-CatCH is a static snapshot of the information collected at the time of publication. The authors do not have a fixed update plan, but welcome any community-driven updates to improve the completeness and accuracy of the database. In case of a new release, it would be assigned a new, versioned, DOI, with a documentation of the provided changes.

Author contributions. YYH, ER and JS conceptualized and designed the dataset. YYH and ER produced the data. YYH conducted the analysis and wrote the manuscript. All authors provided feedback in the process and reviewed the manuscript.

Competing interests. One author is member of the editorial board of the journal Earth System Science Data.

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