IMPACT OF EXTREMES ON HYDRO FORECAST ERROR AND MARKET BIDDING STRATEGIES

Workshop on Forecasting Extremes in the Power System – Sep. 30-Oct.1, 2025

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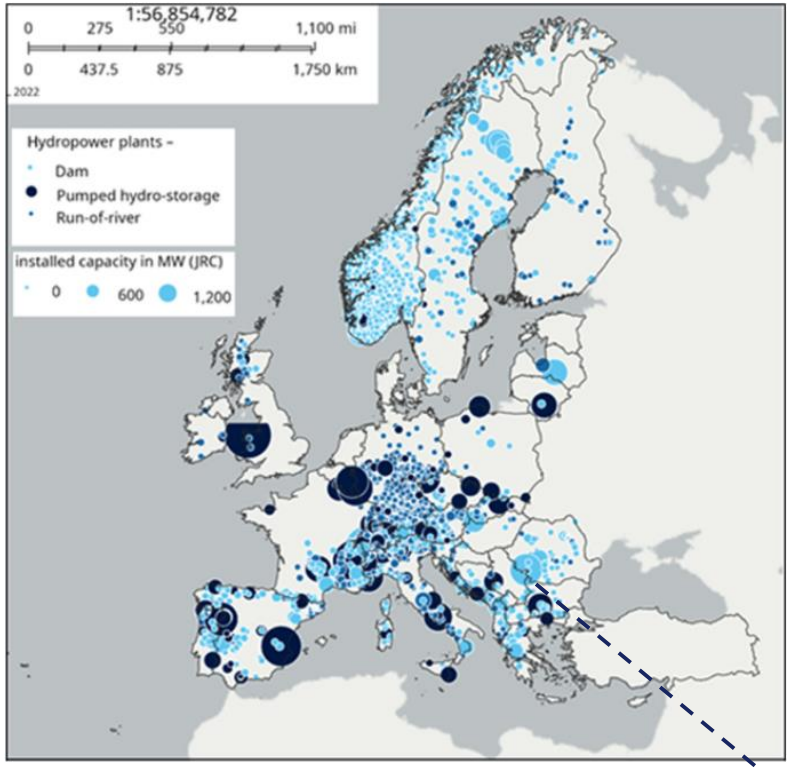
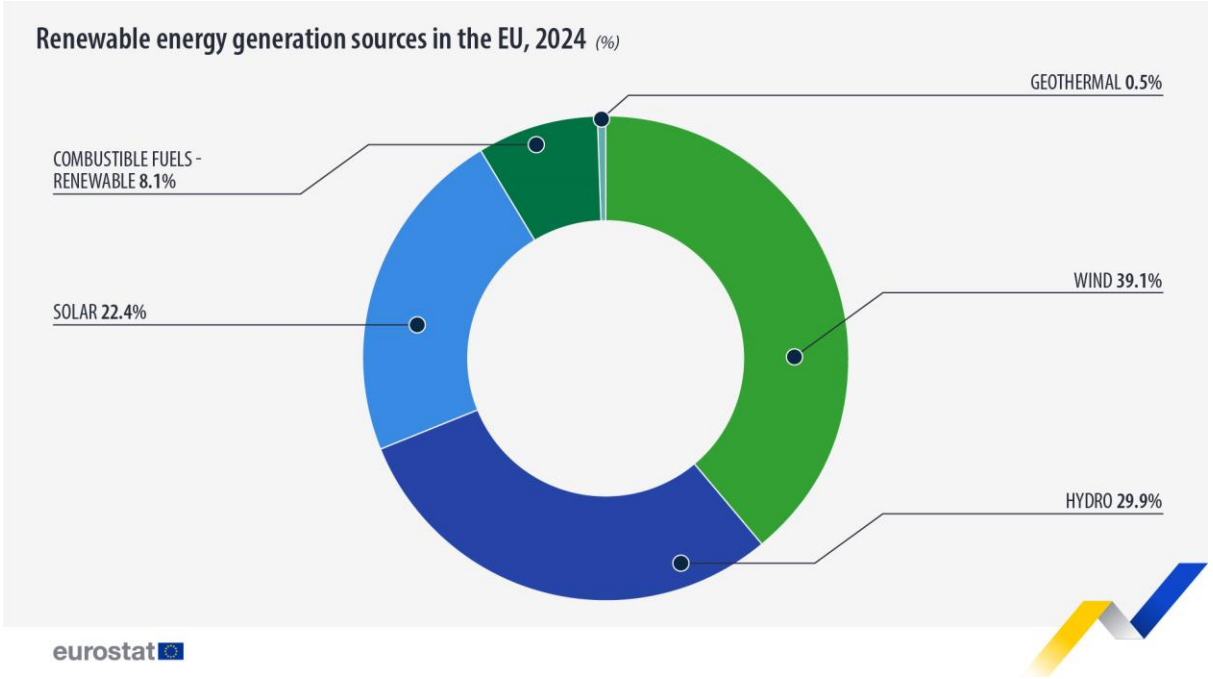
Outline

- Introduction:
  - Hydro power in the EU mix **– Some figures**
  - Daily operational tasks of Hydro Analyst **– Overview**
- Case study:
  - Analysis of an hydro extreme for a selected hydro asset – Showcasing the impact of the forecast on the Profit and Losses (PNL)
- Conclusions **– Take home message**

Introduction: Some key figures about Hydro in Europe



Distribution of hydropower plants in the whole Europe according to the JRC hydropower database (Credit Quaranta 2023)



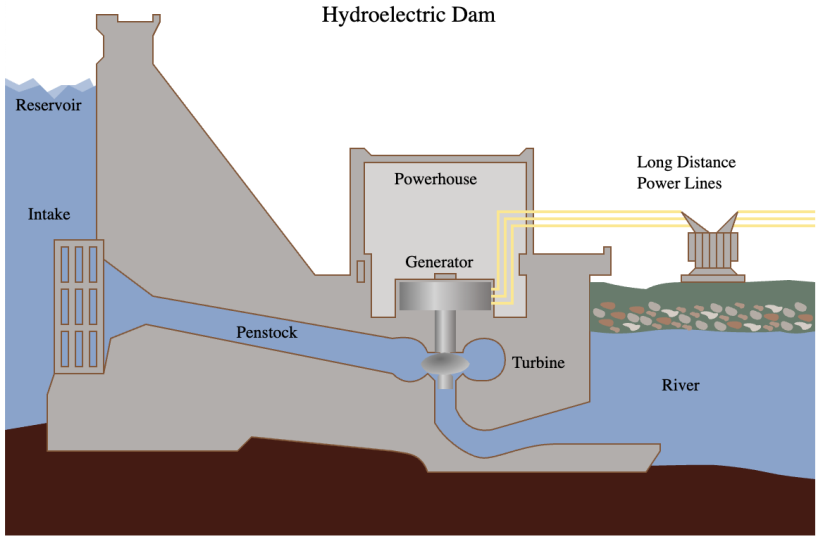
Energy generation source in EU for 2024 (Eurostat 2024)

- Hydro represented 29.9 % of net electricity generation repartition in 2024
- Largest plant installed capacity 2.3 GW : Iron Gates I

Introduction: Daily operational tasks of a Hydro-analyst

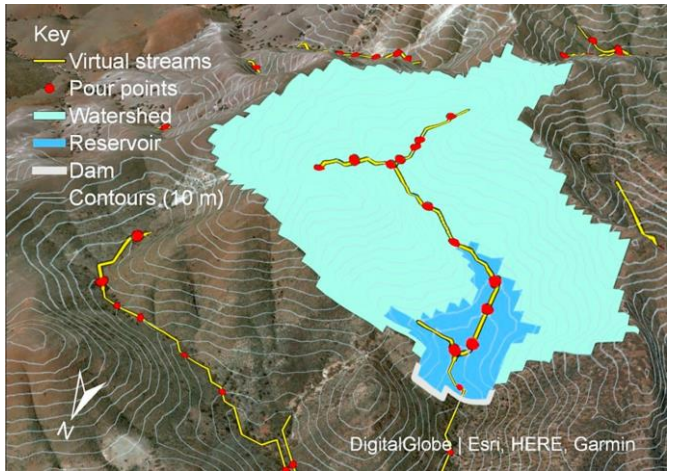
End goal

Know what is the inflows in the reservoir that is available for turbining and electricity generation



Hydro electric dam illustration (Credit Wikipedia)

What issues do we need to solve ?

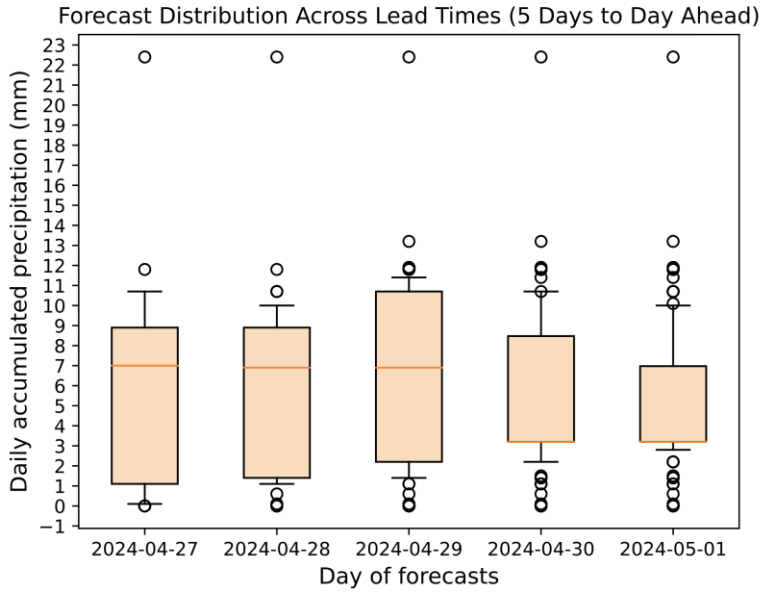


Hydro reservoir and watershed illustration (Credit Lu, Stocks and Anderson 2018)

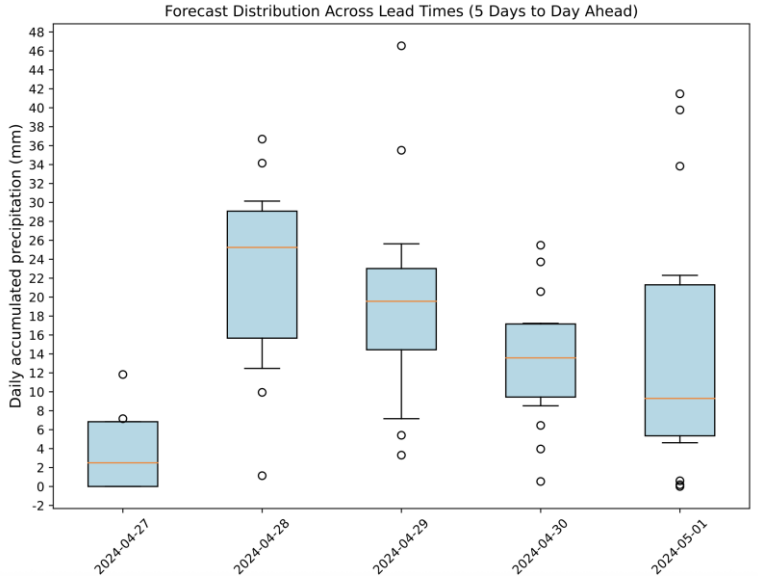
- Are the model able to forecast accurately the precipitation and temperature over the watershed
- In case of model divergence how can the analyst select the most plausible inflow forecast based on available precipitation and temperature provided forecasts

Introduction: Daily operational tasks of a Hydro-analyst

What issues do we need to solve ?



Meteofrance precipitation forecast over a selected hydro watershed (lead time between 5d to 1d)

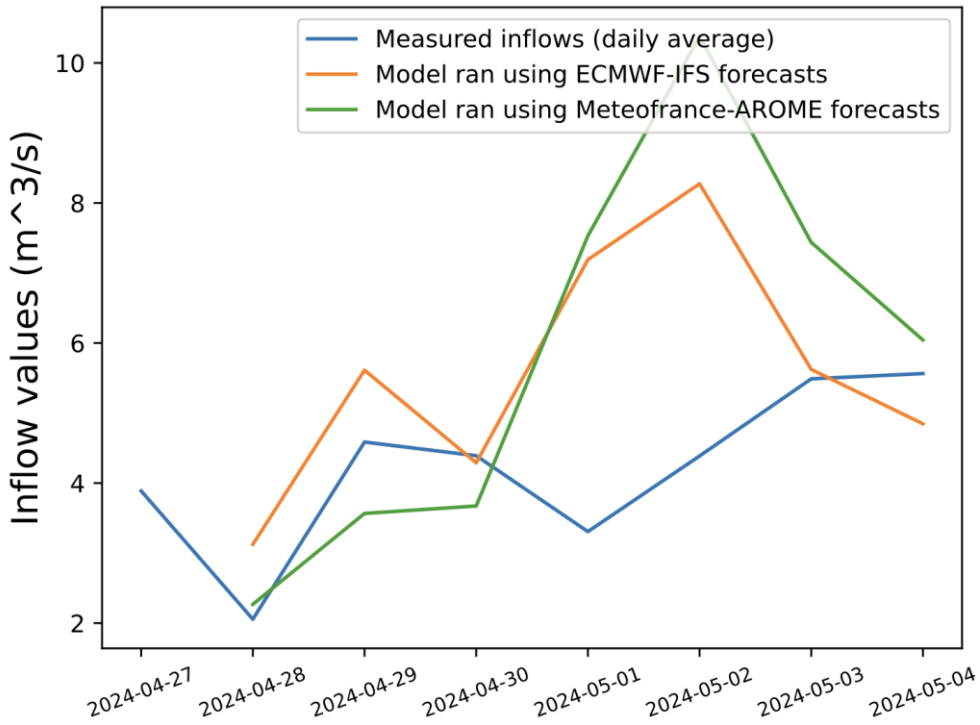


ECMWF-IFS precipitation forecasts over a selected hydro watershed (lead time between 5d to 1d)

- Forecasts indicated:
  - Meteofrance: 23.2 mm daily accumulated on the 29th for the 28-04:00:00 initialized forecasts (day ahead)
  - UKMO: 15 mm daily accumulated on the 29th for the 28-04:00:00 initialized forecasts (day ahead)
  - IFS: 19.56 mm daily accumulated on the 29th for the 28-04:00:00 initialized forecasts (day ahead)
- On the 29th measured precipitation indicated 29.2 mm

Introduction: Daily operational tasks of a Hydro-analyst

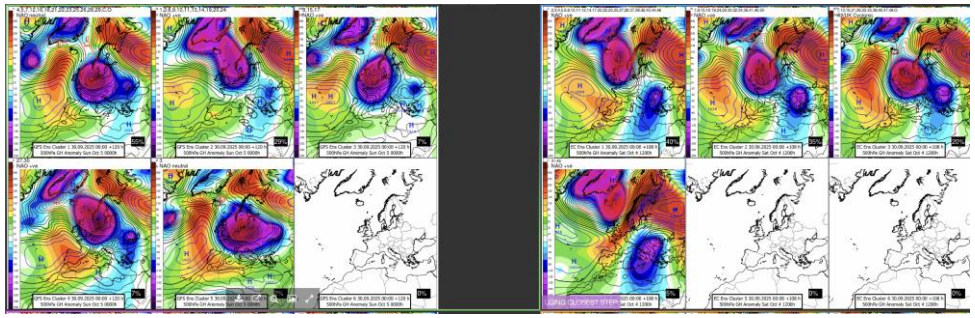
Where is the difficulty ?



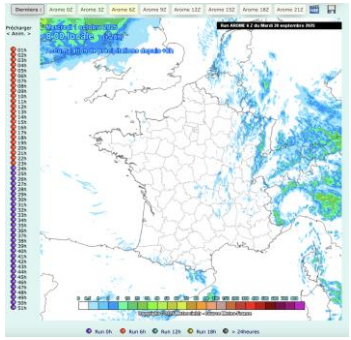
- Which forecast of inflow should we recommend based on available inputs of:
  - Temperature
  - Precipitation

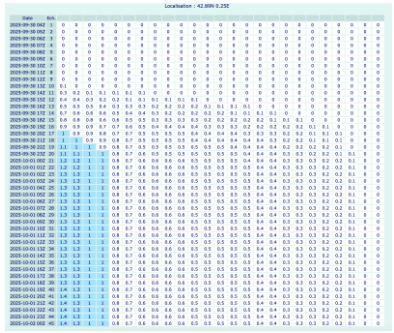
Introduction: Daily operational tasks of a Hydro-analyst

How do we decide: a mix of a lot of things …

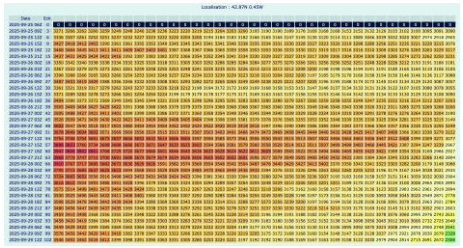


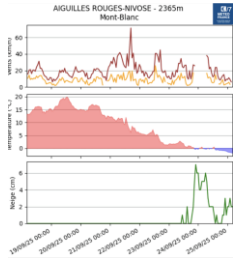
- Looking at weather regimes pressure map anomalies
  - ❑ Assess precipitation and temperature risks based on:
    - High and low location
    - Pressure anomaly
    - Consistency between revision





- Looking at high-res ensemble forecasts
  - ❑ Uncertainty quantification :
    - Assessing deterministic forecast percentile (on that day)
    - How does the daily accumulated compares to historical data at the same period





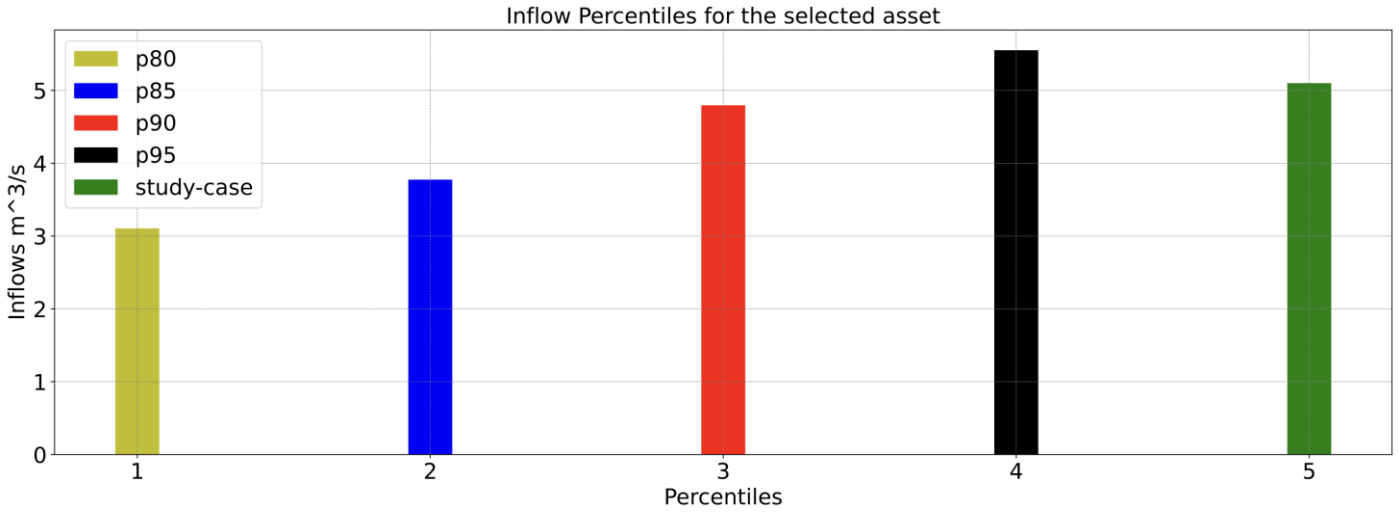
- Tracking freezing levels and snow depth evolution
  - ❑ Assessing the precipitation type:
    - Is it snow that will impact the inflow later than liquid rain

Case Study of a hydro extreme for a selected hydro asset –intraday optimization using day ahead forecasts

- **Location**: Undisclosed
- **Watershed area**: 50 < x < 100 km²
- **Available power:** 90% of installed capacity
- **Total volume of the reservoir:** filled at ¾ (incoming precipitation may cause spilling)
- **Production strategy:** the reservoir level should not increase
- **Forecast horizon:** day ahead
- **Market assumption:**
  - Day ahead clearing price ranging between 100 and174 €/MWh
  - cost of selling electricity Intra-day (3h before delivery) = 18 €/MWh
  - cost of buying electricity Intra-day (3h before delivery) = 71 €/MWh

Hydro damb illustration (Source ECT marine)

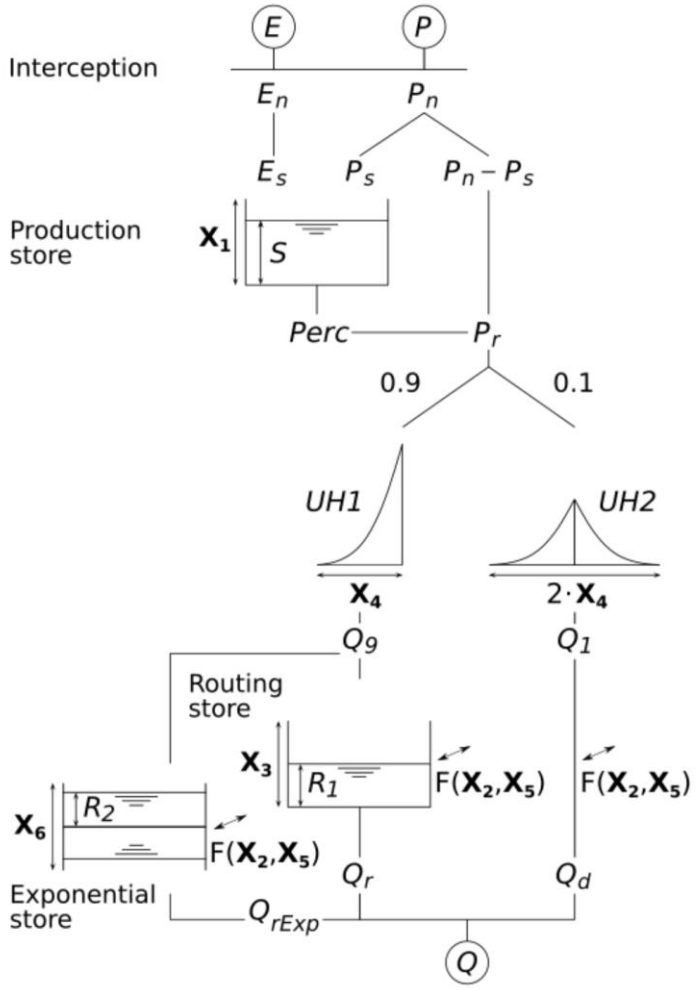
Case Study of a hydro extreme for a selected hydro asset – intraday optimization using day ahead forecasts



Hydro dam illustration (Source ECT marine)

- The inflows received during the study period represent close to a P95 , over the last 20 years, for the select asset → extreme case
- The prices represent one instance of 2024 with the high day ahead clearing prices

Case Study of a hydro extreme for a selected hydro asset : model description



GR6J hydrological model

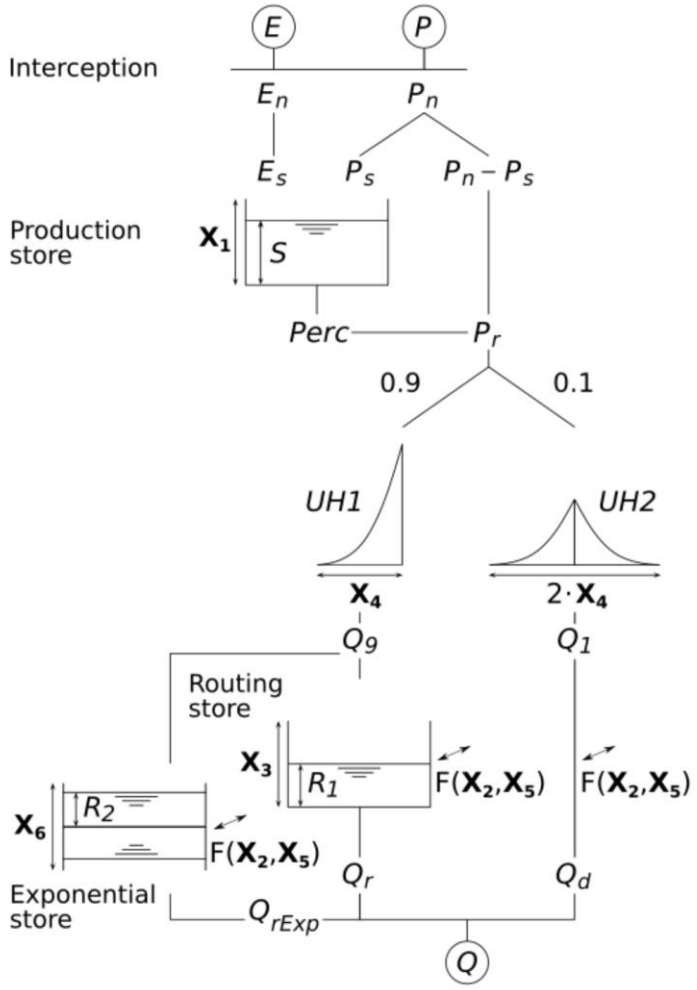
- **Two main modules: Production and transfer modules**

- **Production module**
  - Soil Moisture Accounting: partitions rainfall, into actual rainfall and actual evapotranspiration
  - Water-exchange function simulates groundwater/neighbouring catchment exchanges (import or export of water)

- **Transfer module**
  - Percolation from SMA store
    - effective rainfall split: 10% direct flow, 90% indirect flow
    - two-unit hydrographs (one per flow component)
  - Non-linear routing store for indirect flow

- **Additional feature:** Degree-day snowmelt module for snow-influenced catchments

Case Study of a hydro extreme for a selected hydro asset : model description



GR6J hydrological model

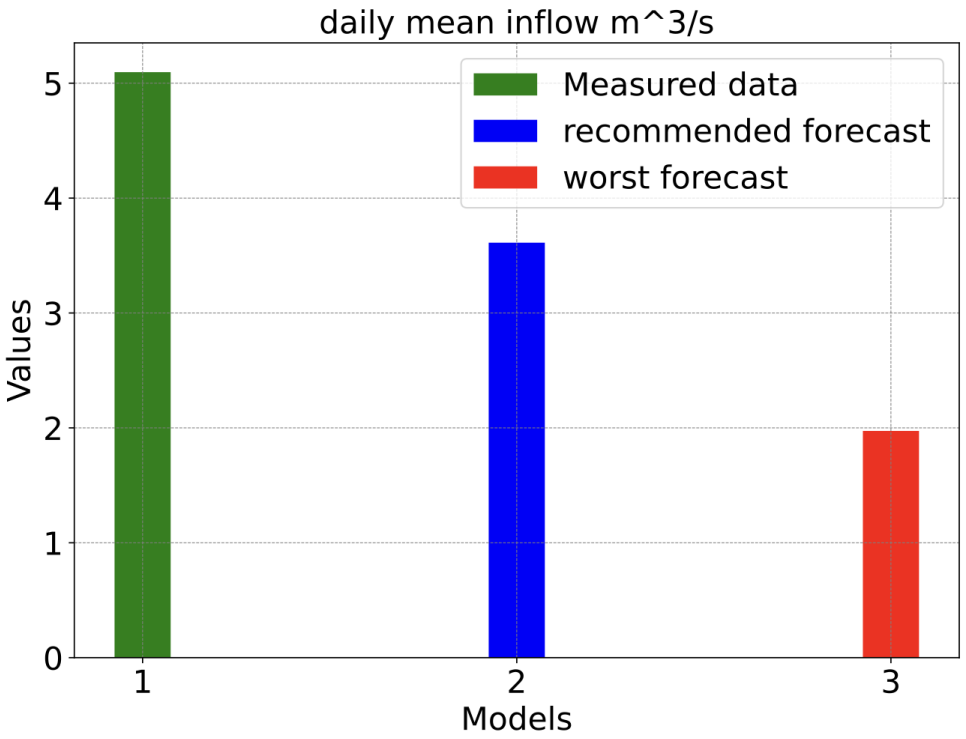
– Model calibration parameters

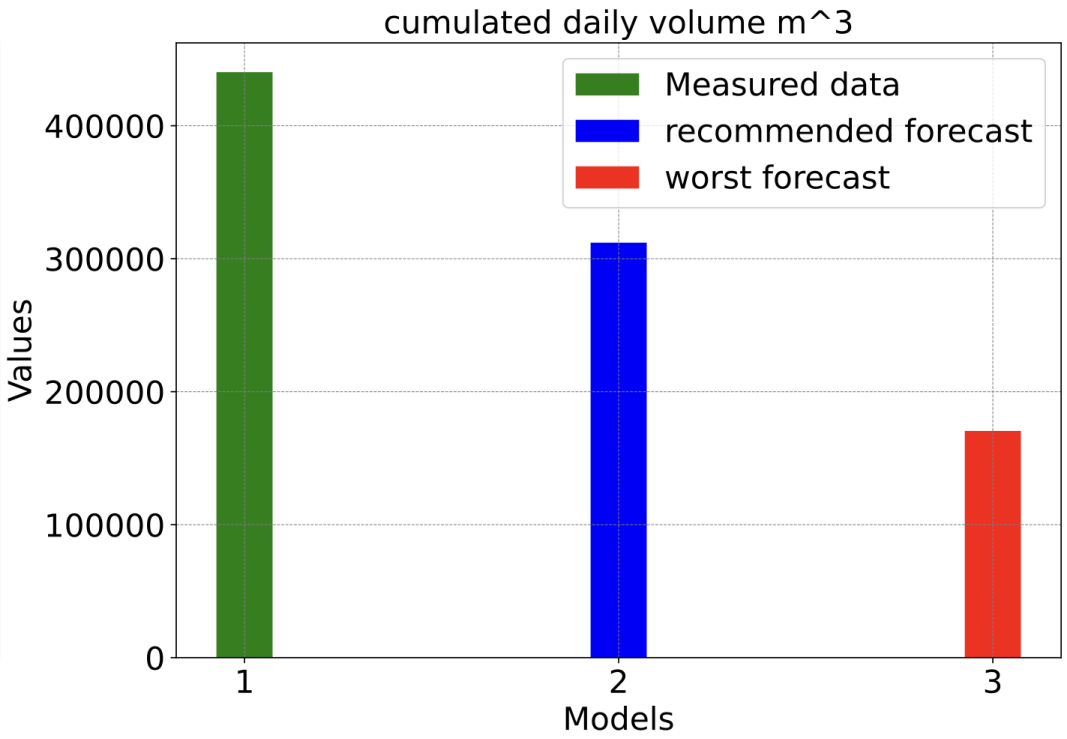
- **X1** : the production store maximal capacity (mm),
- **X2** : the catchment water exchange coefficient (mm/day),
- **X3** : the one-day maximal capacity of the routing reservoir (mm),
- **X4** : the HU1 unit hydrograph time base (days)
- **X5** inter-catchment exchange threshold [-]
- **X6** exponential store depletion coefficient [mm]

– Forecast inputs

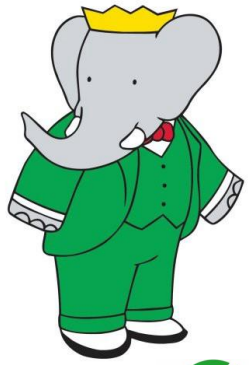
- **P** : precipitation (mm/day),
- **T** : Temperature to compute evapotranspiration (°C),

Case Study of a hydro extreme for a selected hydro asset : daily inflow forecasts





45 000 me !



- **Recommended forecast** (based on the analysis of precipitation and temperatures) underestimate by ~1.2 m^3/s the realized inflow (20% bias)
- Yet the **recommended forecast** **strongly outperforms** the **worst-case scenario** inflow forecast
- The volume difference between the realized and the worst-case scenario amounts to 269770 m^3.

Case Study : Ideal Production plan

day	hours	Captured value (%)	Price day ahead (€/MWh)	intraday_buy €	intraday_sell €
2/2/25	0:00:00	100%	133.26	0	0
2/2/25	1:00:00	100%	126.91	0	0
2/2/25	2:00:00	100%	122.99	0	0
2/2/25	3:00:00	100%	120.66	0	0
2/2/25	4:00:00	100%	122.34	0	0
2/2/25	5:00:00	100%	123.41	0	0
2/2/25	6:00:00	100%	128.09	0	0
2/2/25	7:00:00	100%	135.9	0	0
2/2/25	8:00:00	100%	137.3	0	0
2/2/25	9:00:00	100%	137.7	0	0
2/2/25	10:00:00	100%	130.04	0	0
2/2/25	11:00:00	100%	129.33	0	0
2/2/25	12:00:00	100%	122.24	0	0
2/2/25	13:00:00	100%	111.88	0	0
2/2/25	14:00:00	0%	110.45	0	0
2/2/25	15:00:00	0%	103.27	0	0
2/2/25	16:00:00	0%	101.26	0	0
2/2/25	17:00:00	100%	132.8	0	0
2/2/25	18:00:00	100%	164.67	0	0
2/2/25	19:00:00	100%	173.95	0	0
2/2/25	20:00:00	100%	165.5	0	0
2/2/25	21:00:00	100%	155.77	0	0
2/2/25	22:00:00	100%	148.44	0	0
2/2/25	23:00:00	100%	133.24	0	0

- **Golden production plan**
  - No forecast error (using realized inflows)
  - No price forecast error (bid on the money, called for production)
  - Equipment close to full capacity
- **We produce every hours except for 3 hours**

Approximately the same odds than winning WWTBM once

- **Which percentage** of the **ideal** production plan **revenue** are we **able to capture** using real forecasts ?

Case Study : Production plan from worst forecast

day	hours	Captured value %	Price day ahead (€/MWh)	intraday_buy	intraday_sell
2/2/25	0:00:00	88.90%	133.26	0	0
2/2/25	1:00:00	0%	126.91	0	0
2/2/25	2:00:00	0%	122.99	0	0
2/2/25	3:00:00	0%	120.66	0	0
2/2/25	4:00:00	0%	122.34	0	0
2/2/25	5:00:00	0%	123.41	0	0
2/2/25	6:00:00	0%	128.09	0	0
2/2/25	7:00:00	100%	135.9	0	0
2/2/25	8:00:00	100%	137.3	0	0
2/2/25	9:00:00	100%	137.7	0	0
2/2/25	10:00:00	0%	130.04	0	0
2/2/25	11:00:00	0%	129.33	0	0
2/2/25	12:00:00	0%	122.24	0	0
2/2/25	13:00:00	0%	111.88	0	0
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2/2/25	22:00:00	0%	148.44	0	0
2/2/25	23:00:00	0%	133.24	0	0

Missed opportunities, when comparing to perfect production profile, due to forecast errors

- Because our daily average inflow forecast is not perfect, we need to make **intraday adjustments** (buying or selling) at a cost of 71 €/MWh, 18 €/MWh **instead** of the day ahead price at that hour

Case Study: Impact of the forecast on the Profit and losses (PNL)

Do you have an idea of what would the revenue % of the ideal case that can be captured ?

- ❑ 20-40 %
- ❑ 40-60 %
- ❑ 60-80%
- ❑ None of the above

Case Study: Impact of the forecast on the PNL

- **Recommended forecast** captures 79.38% of the potential revenue
- The **worst-case scenario** captures 52.70% of the potential

Conclusions

- A reliable forecast makes a real difference in hydroelectric management:

  - **Optimizes production planning highlighting the best inflow forecast of the day**
    Aligns generation with expected inflows and market needs

  - **Maximizes market opportunities and revenues**
    Help to plan to capture best prices in the day-ahead market

  - **Minimizes exposure to volatility**
    Reduces losses due to volatile prices in the intraday market

  - **Improves physical risk assessment**
    Enhances accuracy in managing water resources and operational constraints

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