Impacts of Extreme Precipitation on Alpine Reservoirs

Tatjana Milojevic, Michi Lehning

EPFL

CRYOS Cryospheric Sciences

Background

Seasonal shifts in the type and timing of precipitation (Beniston et al., 2018) as well as depletion of glacier mass (Zekollari, et.al., 2019) contribute to the uncertainty of future water supplies to Alpine reservoirs (Carletti et al., 2021; Michel et al., 2022). Compounded onto this is the observed increase over the last century in the overall intensity of extreme weather events in central Europe (Zeder & Fischer, 2020) and the Alpine region, particularly extreme rainfall (Menegoz et al., 2020).

The impacts of climate change are not expected to be felt homogeneously across the whole region and so, without more localized assessment, it can be difficult to ascertain how the risks will differ between individual reservoirs. Seasonal differences can have a large impact on the extreme events observed at a particular time (e.g., Blanchet, Blanc, & Creutin, 2021; Zeder & Fischer, 2020) and should be taken into account.

Estimates of return levels can vary by method (GEV, GPD, eGPD, MEV).

- Selected correct approach for return level calculations based on case (consider data size and return period)
- Adapt to process type and season

Expected Changes

Swiss Alps	Average	Extreme
Winter	Up to +24%	+20%
Summer	Up to -39%	+10%

Expected change in precipitation by end of century, relative to climatology 1981-2010: SCCER-SoE, 2019 & NCCS, 2018

Study Region

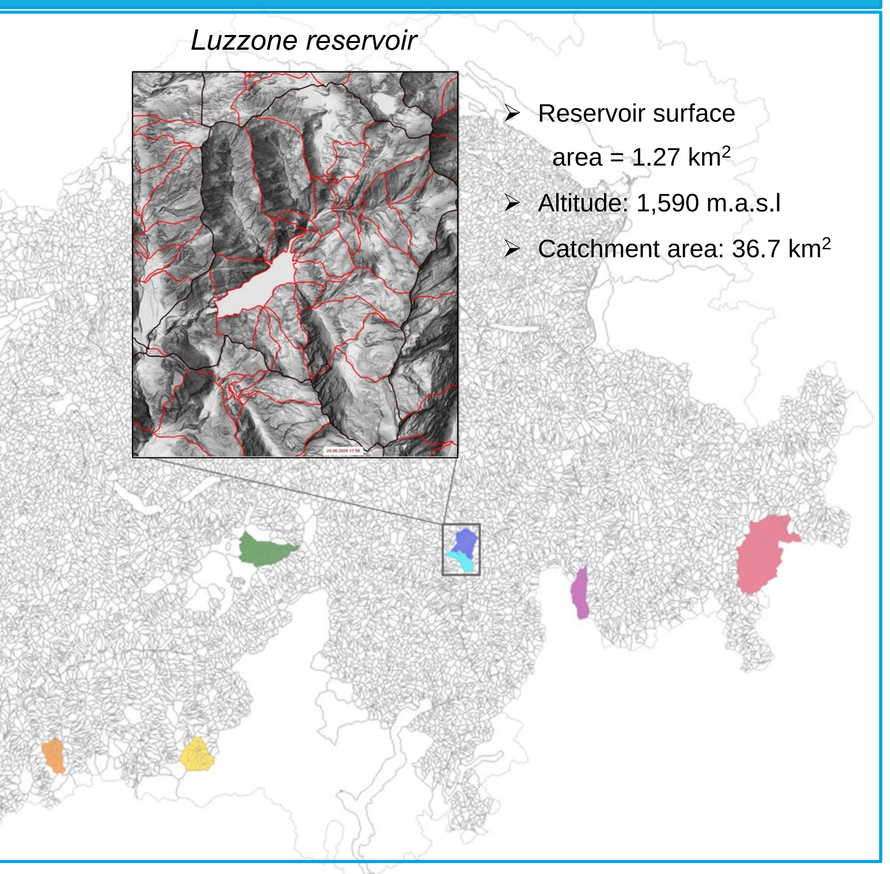
Initial study case: Luzzone reservoir in Ticino

Natural inflows:

- Ri di Luzzone from the east
- Ri di Scaradra from the south
- Ri di Cavallasca form the north

Precipitation data collected at Olivone diga Luzzone station (IDAWEB (2019))

Engineered inflows (from other reservoirs, which may not be hydrologically connected, naturally) also contribute to reservoir water level. For water levels to be sustained during consistent maximum reservoir discharge, ~58% of inflow is from engineered inflows and ~42% from natural inflows.



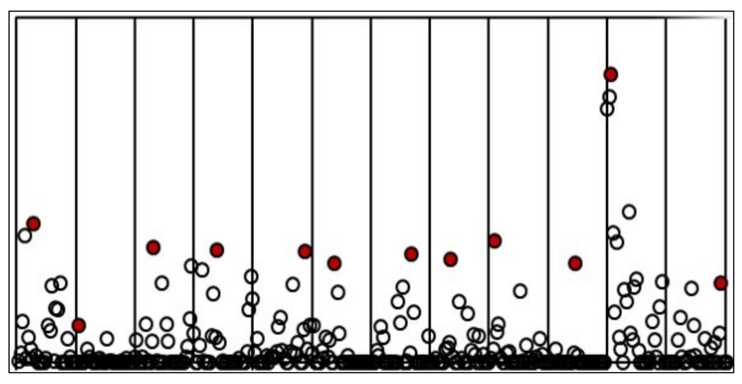
Statistical Methods to fin Return levels (z) for N-year return period

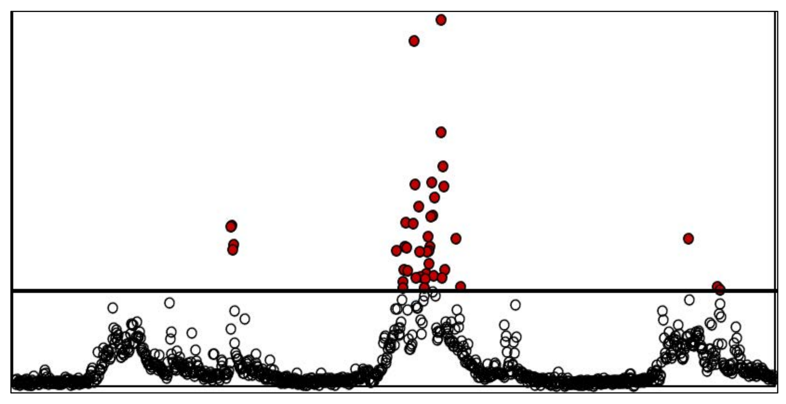
1. Generalized Extreme Value (GEV)

- *Only uses max data points per block (e.g. max per year)*
- *Poor choice for small datasets*

$$z_{GEV}\{N\} = \begin{cases} \mu - \frac{\sigma}{\xi}[1 - \left\{-\log\left(1 - \frac{1}{N}\right)\right\}^{-\xi}], & if\ \xi \neq 0 \\ \mu - \sigma log\left\{-\log\left(1 - \frac{1}{N}\right)\right\}, & if\ \xi = 0 \end{cases}$$

z denotes return levels for period N (years); ξ, σ, and μ are scale, shape, and location parameters, respectively





2. Generalized Pareto (GPD)

- *All data points exceeding set threshold used*
- *More data is used, but still not ideal for small datasets;*
- *threshold selection is critical*

$$z_{GPD}\{N\} = \begin{cases} u + \frac{\sigma}{\xi}[(N\, n\zeta_y)^{\xi} - 1], & if\ \xi \neq 0 \\ u + \sigma \log(N\, n\zeta_y), & if\ \xi = 0 \end{cases}$$

z denotes return levels for period N (years); ξ, σ, and u are scale, shape, and location (threshold) parameters, respectively

3. Extended GPD (eGPD)

- *all positive data used*

$$z_{eGPD(N)} = F^{-1}\left(1 - \frac{1}{Nn_p}\right) = \begin{cases} \frac{\sigma}{\xi}\left[\left\{1 - G^{-1}(1 - \frac{1}{Nn_p})\right\}^{-\xi} - 1\right], & if\ \xi > 0, \\ -\frac{\sigma}{\xi} log\left\{1 - G^{-1}\left(1 - \frac{1}{Nn_p}\right)\right\}, & if\ \xi = 0, \end{cases}$$

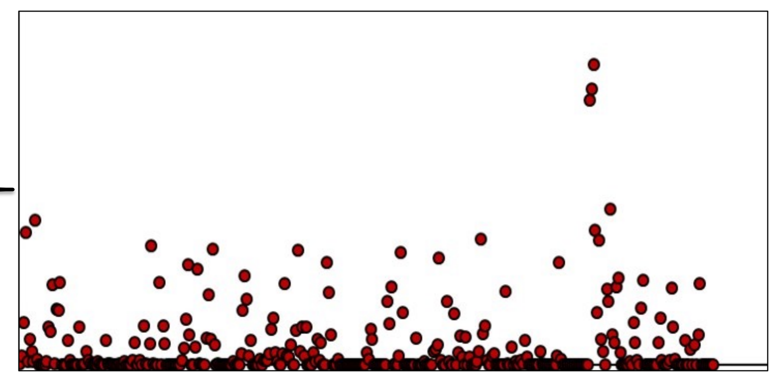
z: return levels for period N (years); ξ, σ, and n_p are scale and shape parameters, and number of positive data points, respectively

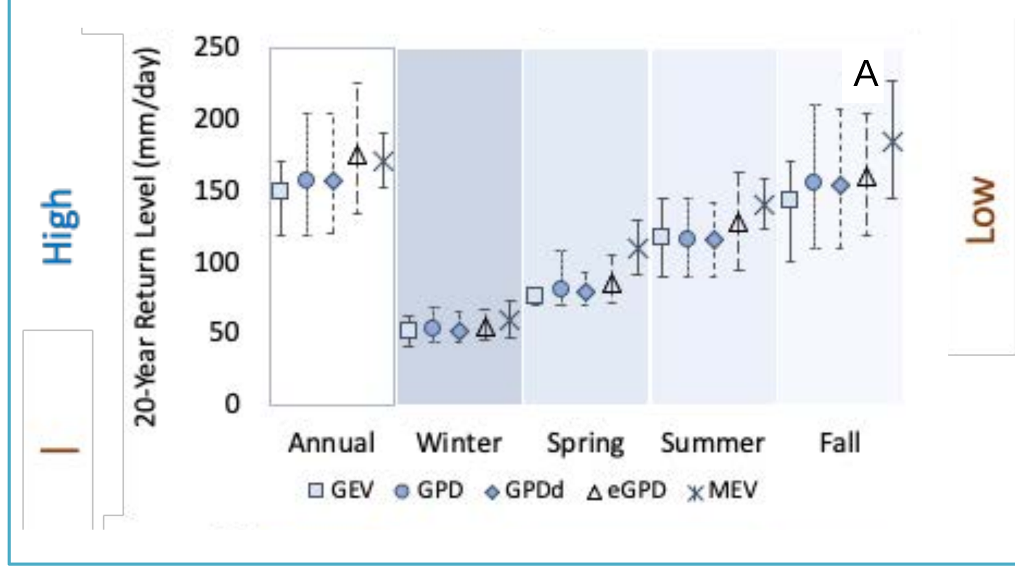
4. Metastatistical Extreme Value Distribution

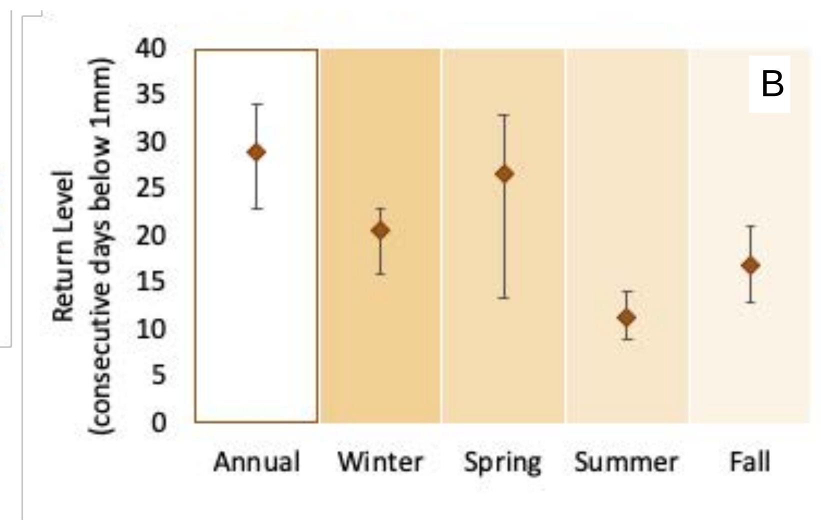
- *all positive data (shown for Weibull distribution)*

$$H(x) = \frac{1}{T}\sum_{j=1}^{T}\left[1 - exp^{-\left(\frac{x}{C_j}\right)^{w_j}}\right]^{n_j}$$

$$z_{MEV(N)} = H^{-1}\left(1 - \frac{1}{N}\right)$$





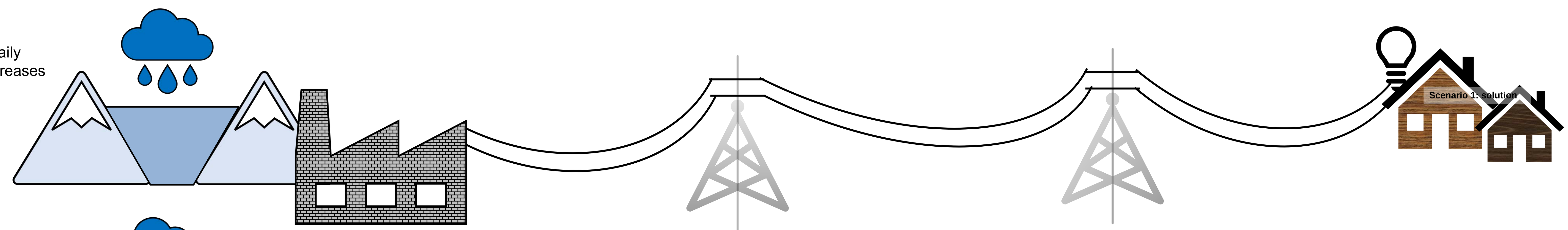


Scenario Impact Examples

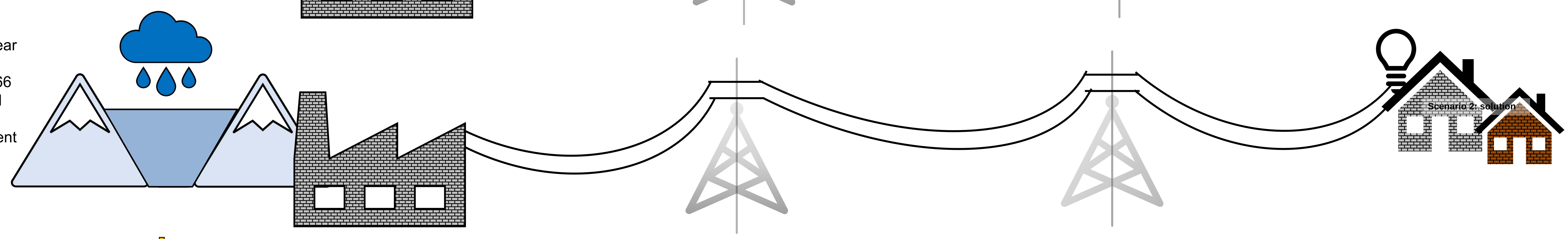
Select a scenario and check if the reservoir will be able to generate electricity demanded:

Assumed conditions: aim to generate same amount of electricity (constant demand) only change in natural inflow sources (not from neighboring reservoirs) is in precipitation

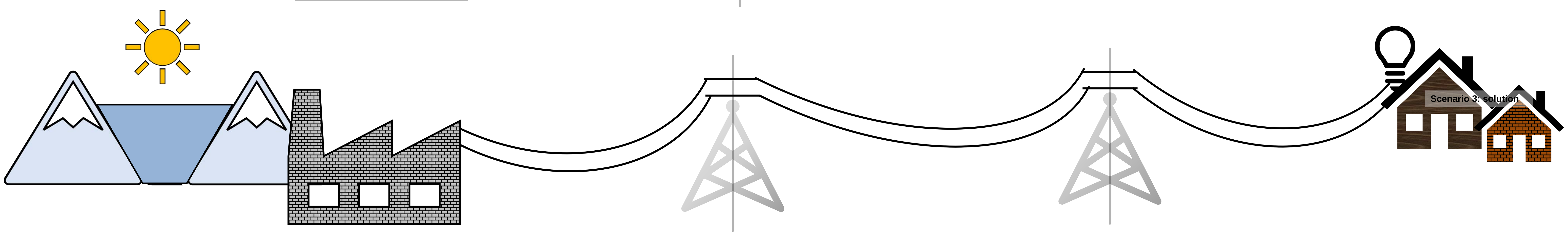
Scenario 1:
Historical maximum daily precipitation event increases in frequency by 10%.



Scenario 2:
Historical winter 20-year extreme precipitation increases by 20% to 66 mm/day, falls as liquid rain rather than snow across whole catchment



Scenario 3:
Winter snow decrease



Future Work

The following areas will be focus of future work:

- Investigate the spatial extreme of extreme storm events and how they may change according to different climate scenarios
- Will these storms impact multiple reservoirs or are their particular vulnerabilities in the network
- Assess future trading and management options when climate driven extremes are considered vs historical approach

Methods

- Synthetic data to simulate realistic extreme event scenarios will be generated using stochastic weather generator
- extreme event realizations will be used as input into the physically-based model Alpine3D to generate runoff, particularly considering the snowmelt cases in winter
- The overland runoff will be converted into inflow for each reservoir in question
- Stochastic optimization model will be used to assess energy production potential of each scenario

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