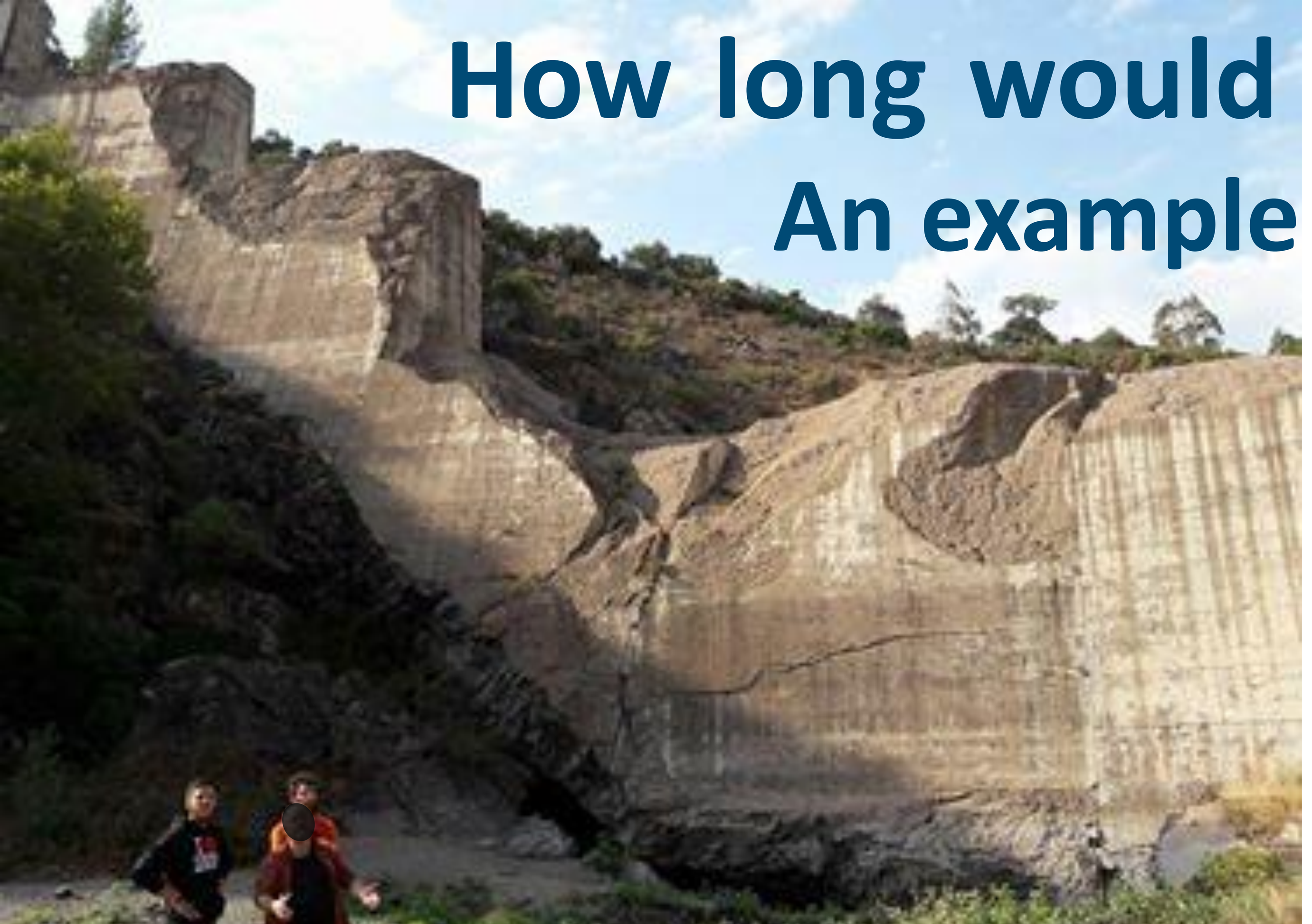
The ruins of the Malpasset dam, september 2017

How long would we have to wait before (re)filling the Malpasset dam reservoir?

An example of a teaching project done using R and airGR modeling packages

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1 Introduction and objective

The Malpasset dam – located in Fréjus, on the Reyran river (South of France) – gave way on December 2nd 1959, causing great damage and hundreds of casualties. It is now a ruin. This work aims at answering the following question: **if the dam were rebuilt identically, how long would we have to wait before filling its reservoir?**

Several basic estimations of the reservoir filling time were made, considering that the dam would be rebuilt during the 2018 summer. A statistical analysis of the historical incoming flows was made using R, based on the observed local climate series and the measured flows of the Reyran river over the last decades. A more realistic timetable would have the dam rebuilt around 2050, in a potentially different climate. Estimations of the Reyran catchment incoming flows in a future climate were therefore computed. To do so, a monthly rainfall-runoff model called GR2M[(a)], applied within the airGR[(b)] and airGRteaching[(c)] packages was used.

2 Datasets and methodology

The Malpasset dam was built on the Reyran river, draining a 47 km² catchment (cf. Fig. 1), resulting in a reservoir capacity of 48 Mm³.

Data used:

- *Historical climate:* 3 daily meteorological series (precipitation and air temperature) are available (source: Météo France, cf. Fig. 1).
- *Historical streamflow:* a daily streamflow series is available (source: Banque HYDRO) downstream from the Malpasset dam, at Fréjus (cf. Fig. 1).

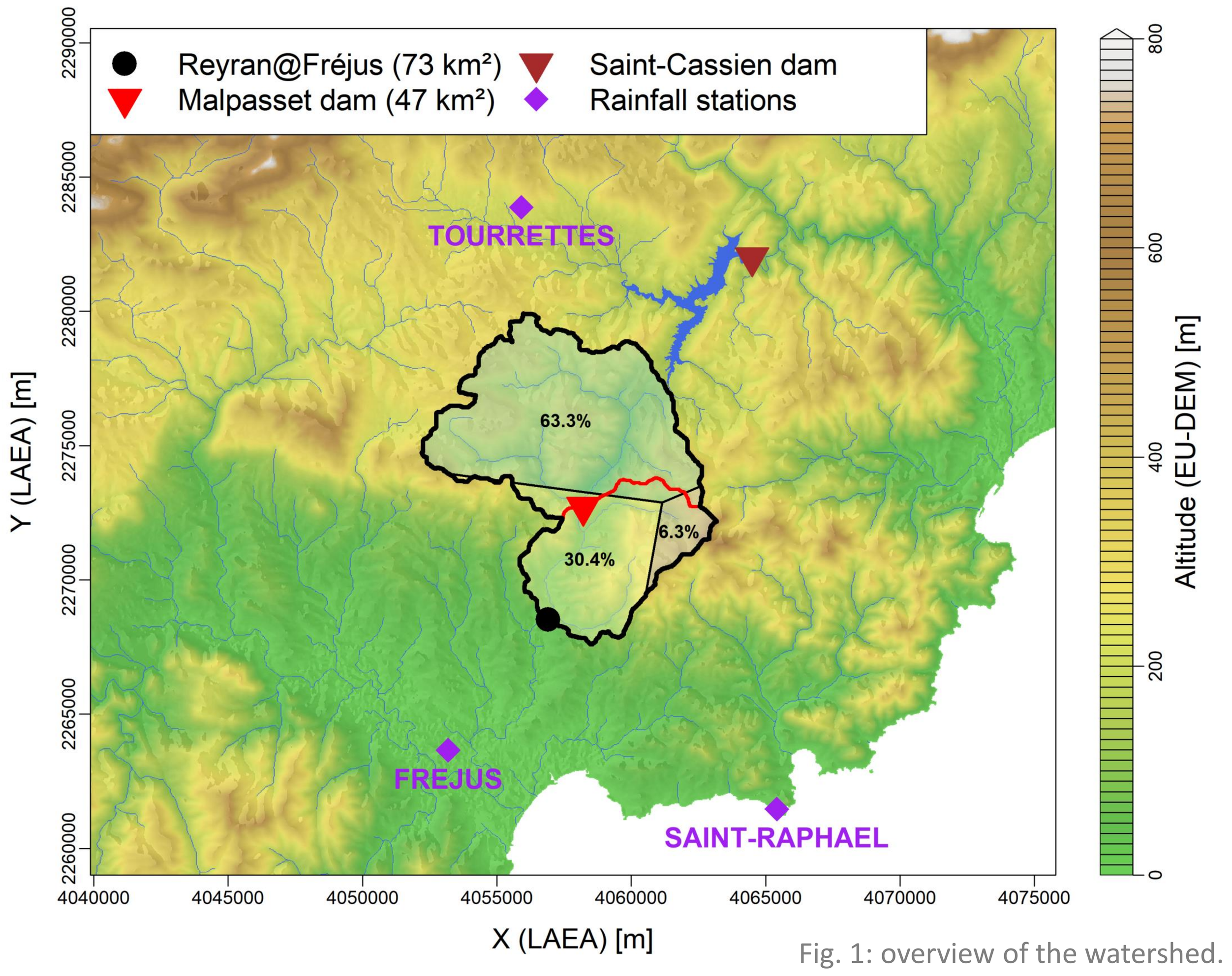

Fig. 1: overview of the watershed.

Frequency analysis of historical inflows for the estimation of the filling time under current climate:

- Frequency analysis of annual flows at Frejus is done to have annual inflows at Malpasset (Q_{in}), considering two periods (1972-2012 and 1994-2012).
- Reservoir evaporation (E_{res}) is quantified using previous studies[(d)] on the neighbor Saint-Cassien reservoir (cf. Fig. 1): mean annual E_{res} = 7.5%.
- Minimum instream flow (Q_{min}) is assumed to be the minimum monthly discharge with a 5-year return period (Q_{MNA5}), here Q_{MNA5} = 1.5 l/s.
- 100 series of annual reservoir inflows (I_n) are generated for each studied period, using the following water balance equation:

$$I_n = Q_{in} - E_{res} - Q_{MNA5} \quad \text{(Eq. 1)}$$

Rainfall-runoff modeling for the estimation of the filling time in a future climate:

- Future climate estimated through a basic delta approach (± of monthly mean of precipitation (P) and air temperature).
- Catchment precipitation estimated using three stations and Thiessen polygons (cf. Fig. 1).
- Calculation of potential evapotranspiration (PE) using Oudin formulation[(e)].
- Calibration (and validation) of the monthly rainfall-runoff model GR2M on the historical period, with the Nash & Sutcliffe (1970)[(f)] objective function.
- Simulation of future inflows using the previously calibrated rainfall-runoff model.
- Application of the water balance equation presented in Eq. 1.

3 Filling time under current climate

Annual inflows (Q_{in}):

The observed annual flows are depicted on Fig. 2a. They follow a log-normal distribution for both periods (cf. Fig 2b).

A downscaling was applied, since the data refer to the Fréjus station, when the Malpasset dam is located slightly upstream (Fig. 1).

A coefficient worth 0.644 corrects the values of flows (obtained from the ratio of the surfaces of the two watersheds).

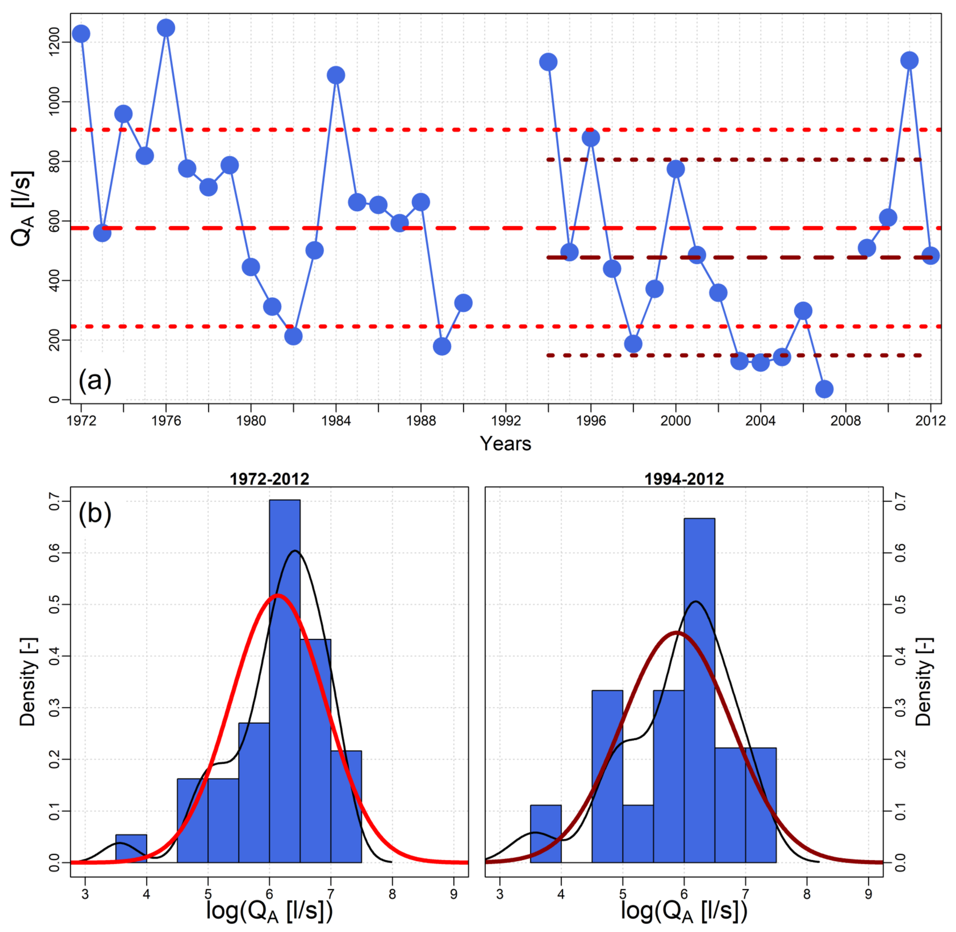

Fig. 2 a: Annual flow measured at the Fréjus station,
b: Distribution of the flows for the 1972-2012 and the 1994-2012 periods.

Reservoir evaporation (E_{res}):

The lake evaporation E_{res}, once converted into l/s, amounts to 158.4 l/s and can be subtracted to the generated flows.

Estimation of filling times:

The temporal evolution of the quantity of water in the reservoir is shown in Fig. 3a. The distributions of the filling times for the exact reservoir capacity are visible on Fig. 3b.

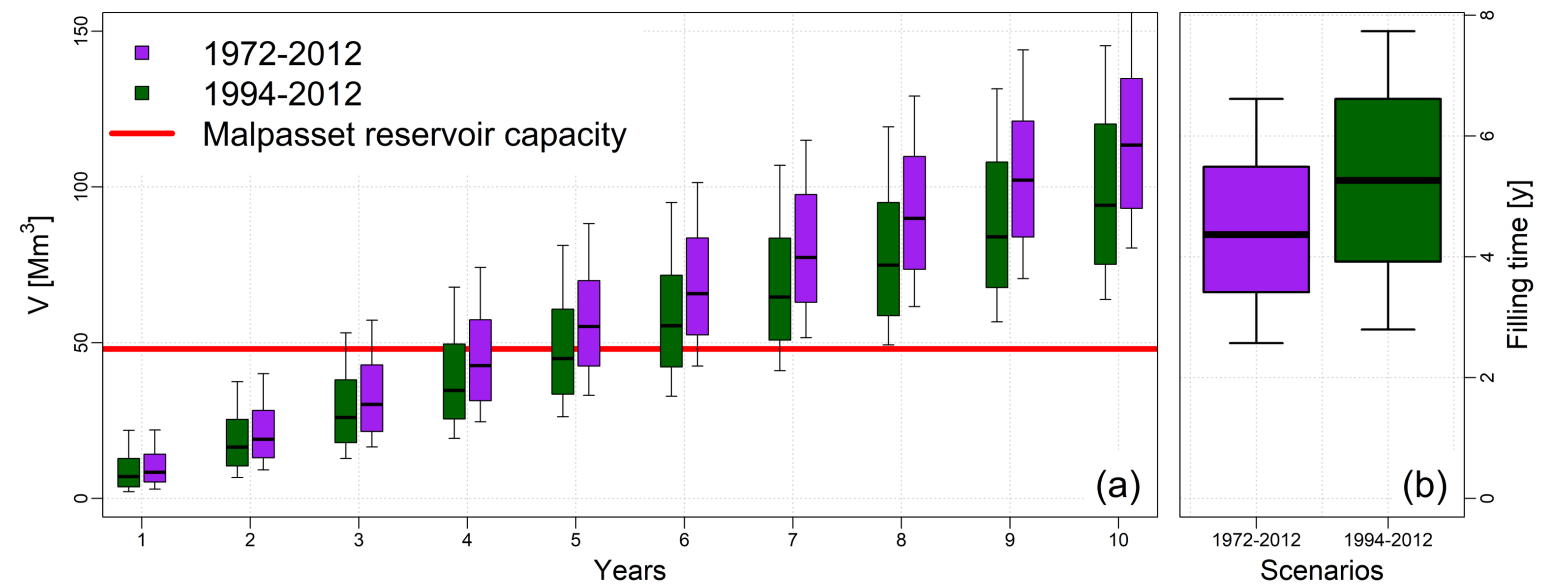

Fig. 3 a: Water volume accumulated in the reservoir, b: Distribution of the filling time for each scenario.

Conclusion

- Filling the Malpasset dam reservoir in a future climate could be challenging, since the PE would take away most of the water accumulated (in the lake).
- To further estimate the time required, other climatic scenarios could be used, such as the RCP ones proposed by the GIEC within the Coupled Model Intercomparison Project.
- Then the reservoir evaporation could be computed accurately. Indeed, it was here considered constant (E_{res}) and independent from the future air temperatures, which is a strong assumption.
- **Both used R packages (airGR and airGRteaching) happened to be rather intuitive and helpful to efficiently carry out such a project, by performing an easy-to-understand rainfall-runoff modeling within the R environment.**

4 Filling time in a future climate

To estimate the future flows, the GR2M rainfall-runoff model was chosen. The two input variables it requires are monthly precipitation and potential evapotranspiration.

1. **Determination of the catchment precipitation (current and future):**
   A study carried on a nearby watershed (Durance) provides probable precipitation deltas in a future climate (Sauquet *et al.*, 2015)[(g)]. These deltas, shown on Fig. 4a, were added to the catchment precipitation values calculated with Thiessen's polygons, as shown on Fig. 1.

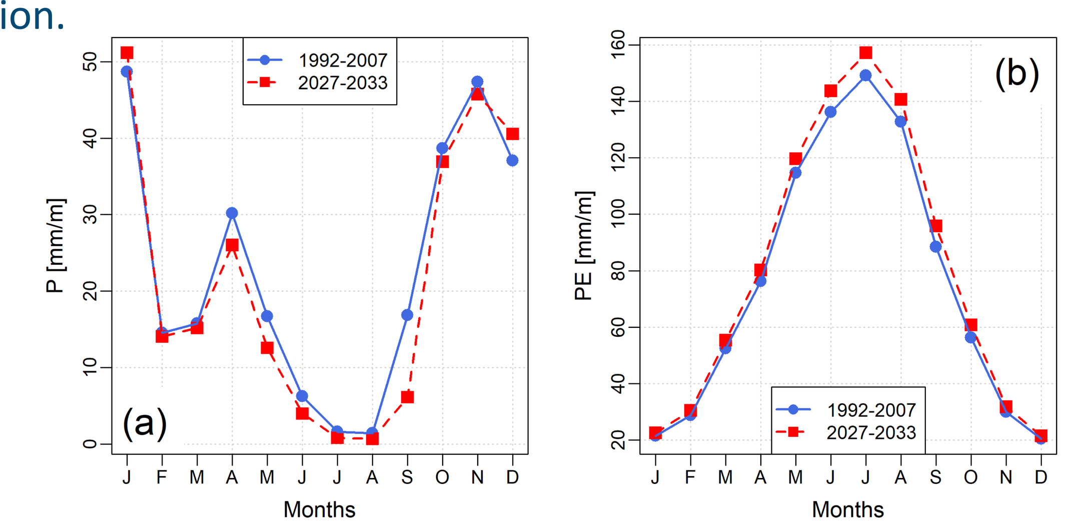

Fig. 4 a: Monthly precipitation, b: Monthly PE.

2. **Calculation of the catchment future PE:**
   Sauquet *et al.* (2015) also provided PE deltas (see Fig. 4b). Here again, they are added to the monthly PE values obtained from Oudin formula.

3. **Calibration and validation of the GR2M rainfall-runoff model:**
   Before it can be used to determine future flows, the model must be calibrated from historical measurements. The NSEs and differences between simulated and observed flows are visible on Fig. 5. With the two calibrated parameters, the future flows can be simulated.

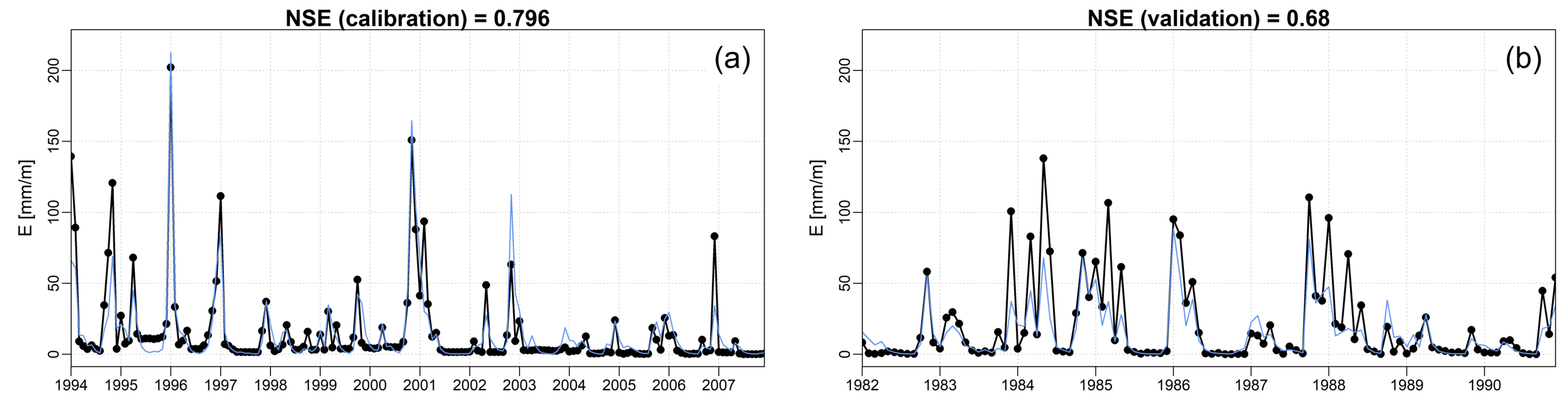

Fig. 5: Difference between the simulated and measured flows for the calibration (a) and the validation (b) periods.

4. **Estimation of the filling times:**
   Two approaches exist. The first one consists in adding up the generated monthly flows, since each is definite in time. Using this method, the reservoir would be filled in a slightly longer time than under current climate (see Fig. 6a). The second one consists in repeating the frequency analysis process, with the simulated flows (both in current and future climate). The distributions of the 100 filling times calculated can be seen on Fig. 6b.

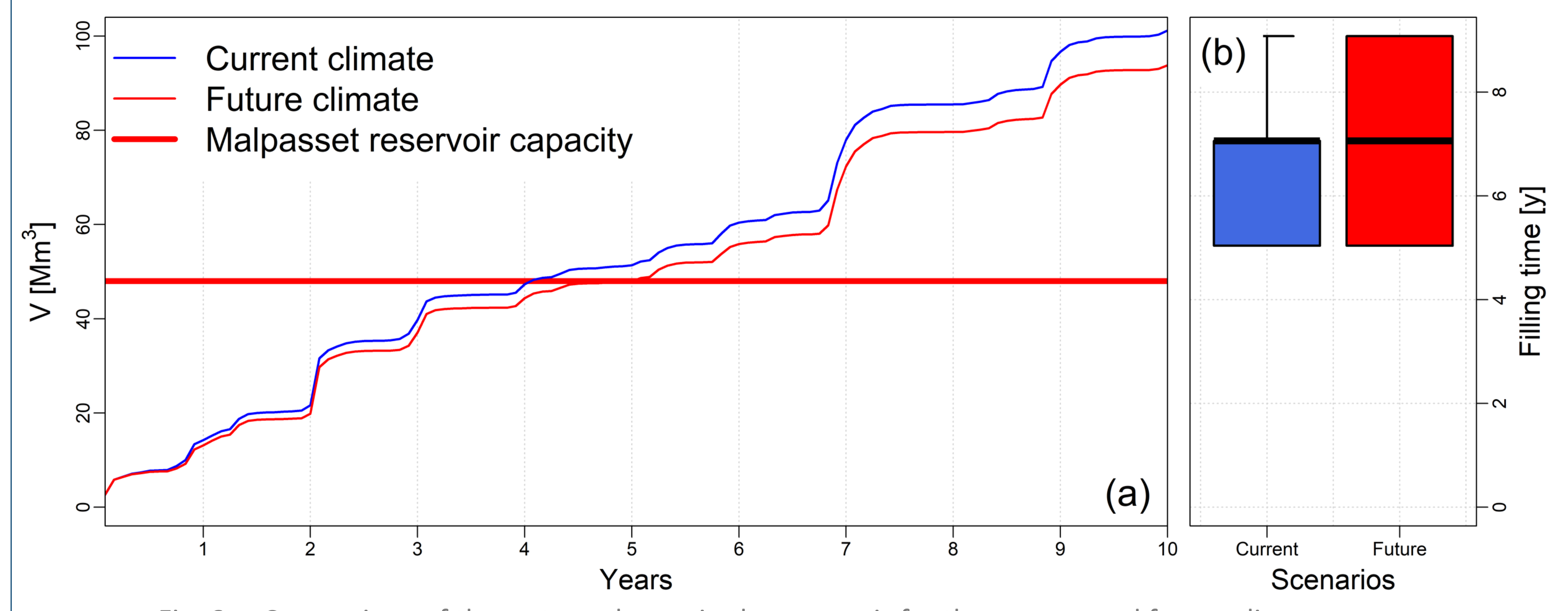

Fig. 6 a: Comparison of the water volumes in the reservoir for the current and future climate,
b: Distribution of the filling times simulated from the GR2M simulated flows.

References:

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(g) Sauquet *et al.* (2015): R²D² 2050 project final report. 245 pp.