A Safe Operating Space Framework to Assess the Future of Reservoir Operations at the Catchment Level

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This study was developped within the European STARS4Water project and aims at developping an application of the Safe Operating Space concept at the catchment level, to address water management concerns and the future of the water resources, and inform policy-making and governance efforts toward global sustainability.

It has 3 main goals:
- *Support a better understanding of risks and vulnerabilities*
- *Knowing the risk, searches for operational safety, safe processes and risks to be aware of*
- *Guide sustainable water management and governance at regional and local scales*

The STARS4Water project

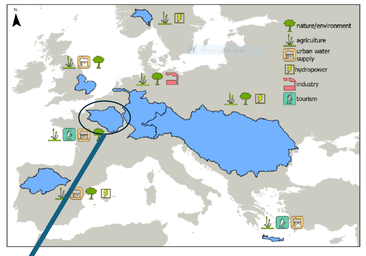
Creates new generation data services and data-driven models tailored to stakeholders needs and requirements

Enhances the knowledge base and the scientific underpinning of climate risks and impacts at river basin scale

Improves decision making by stakeholders through the development of dashboards and a safe operating space framework

Co-design with stakeholders in 7 river basin hubs

STARS4Water River Basin Hubs



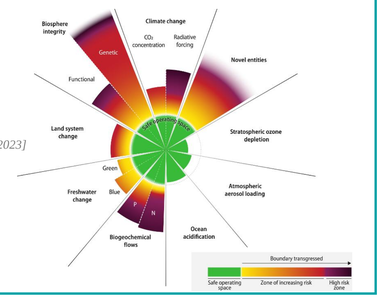
The Safe Operating Space (SOS) Concept

Principles come from the 'planetary boundaries' framework: SOS for humanity with respect to the **anthropogenic pressures on the Earth System.** It defines **the « safe limits » for humanity**, with respect to the multitude of pressures caused or influenced by humans on the Earth System and its natural environment.

It has been adapted to focus on the water cycle and the **pressures on water resources**:
- Holistic assessment of water availability
- Envisioning **the future through water management scenarios**
- Evaluating **boundaries and the risk of crossing thresholds**
- Understanding our **current operational adaptive capacity**

Adaptation of the concept at regional / local scale

[Richardson et al. 2023]

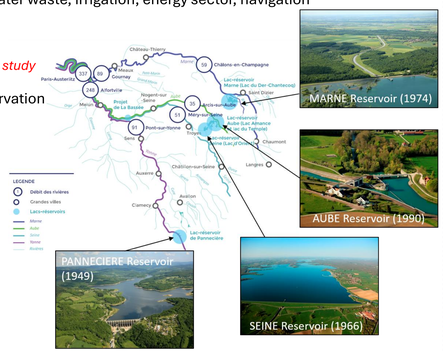


1) Case study of the Seine River catchment

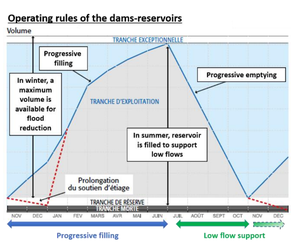
- 17 million of inhabitants on the catchment
- Several water users: drinking water and water waste, irrigation, energy sector, navigation

4 lakes-reservoirs, 3 objectives
- Flood protection
- Regulation of low flows
- Biodiversity & aquatic ecosystems preservation

Focus of this study

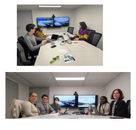


Operating rules of the dams-reservoirs



https://www.seinegrandslacs.fr/

2) Co-construction of the research question



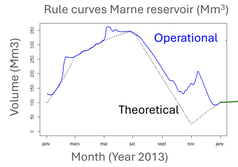
Aim to identify
- **Key concerns** and operational questions
- **Tools** currently in use and available **data**
- **Relevant indicators** and meaningful threshold values
- Representation of **future conditions**
  - Climate scenarios
  - Management scenarios

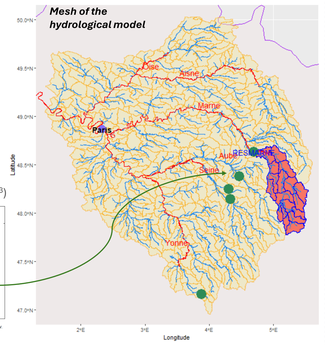
What if the upstream reservoirs cannot fulfil their management objectives in the future (e.g. more severe low flows)?

Modelling framework:
- **Semi-distributed hydrological model GRSD** (with multi-variate calibration)
- **Module for reservoir management** (direct withdrawals/injections to take into account theoretical and operational rule curves)

[Collignan et al., 2026]

Rule curves Marne reservoir (Mm³)



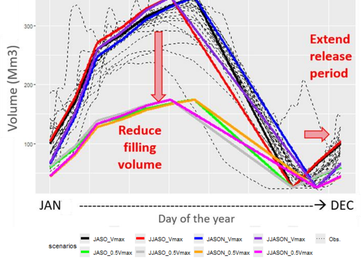


3) Scenarios

To build **plausible** narratives that explore the **boundaries** of the climate system within the limits of the management system

Management scenarios + Climate projections

Marne reservoir
Reservoir volume : Scenarios and variation from 2000 to 2020



Selection of 4 contrasted scenarios (EXPLORE 2) [Heraut et al., 2024]

Less warm, less humid → Hotter, drier

Precipitation anomalie (2000-2020/ 2070-2098)

	CNRM-ALADIN	MOHC--ALADIN	MOHC--CCLM4	ICHEC--MOHC
Avg over the year	+	+	+	- -
Filling period	-	+	++	- -
Release period	++	+	- -	-

Illustrated in this poster

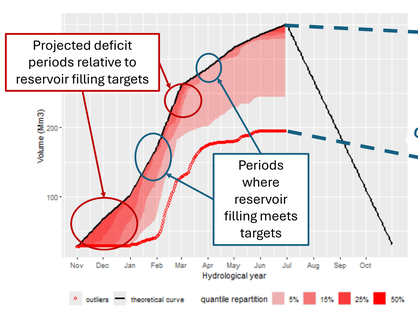
4) Results

For the most extreme climate scenario: drier and hotter (ICHEC –MOHC), 2070-2098 period

1 Filling the reservoir by July (risk of filling deficits)

Marne reservoir

Probability of deficit occurrences for each day of the filling period, for 2070-2098



2 Low flow support downstream the reservoir (risk of crossing thresholds)

Defined legal **thresholds** for water restrictions, for the main gauging stations downstream of the reservoirs

Crisis | Reinforced alert | Alert | Warning

Average number of days in a month below each threshold

A Plausible management scenarios

Varying the length of the release period (J: June, J: July, A: August, S: September, O: October, N: November)

Ex: Gauging station in Paris

JASO | JJASO | JASON | JJASON

50% of the time

Once in 30 years

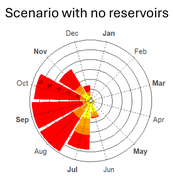
Varying the initial filling of the reservoir

Reservoir full — Vmax (100%)

Reservoir half empty — 0.5Vmax (100%)

Increase of risk (crossing alert threshold)

Scenario with no reservoirs



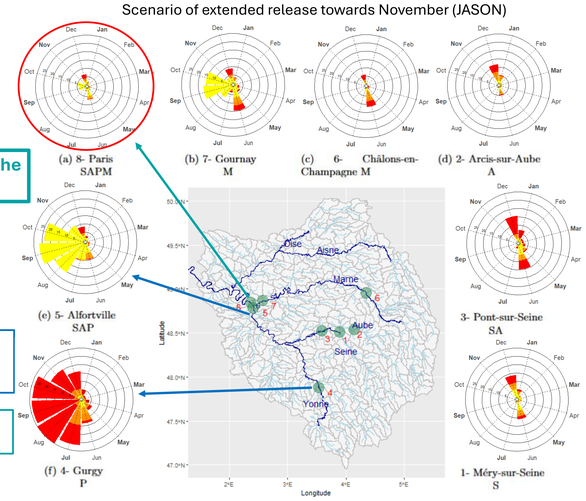
Best scenario : extending the release period towards November

B Spatial variability of the best scenario

South of the catchment: → Smaller reservoir, not sufficient to support low flows

Partially compensated for, after confluence of all rivers

Scenario of extended release towards November (JASON)



Conclusion and perspectives

- **For stakeholders:** relating risks to operations, with focus shift from quantifying all sources of uncertainty to addressing 'what-if' scenarios
  - Seine: under drier climate scenarios, need to extend low-flow support in time, and to ensure reservoir filling
- **For researchers:** storylines offer a more tangible research-to-operations approach
  - Exploring extremes ("stress test") and interactions with human (management) actions
  - Intensive co-creation with stakeholders (recognizing the value of continuity in the engagement process)
- **Challenges & Perspectives:**
  - Analysis specific to a given concern : focus needed for achieving effective management purposes
  - Importance of working with additional indicators and thresholds that are meaningful to stakeholders and operations

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- Collignan et al., 2026. The added value of considering evapotranspiration fluxes in the calibration of a semi-distributed hydrological model, Intl. J. River Basin Management. DOI: 10.1080/15715124.2026.2711679
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